ERDC/CERL TR-07-37

Construction Engineering Research Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Annex 46 Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)

Energy and Process Optimization Assessment at U.S. Army Installations in Germany

Keiserslautern Army Depot, Piermasens Army Depot, Katterbach Kaserne, Storck Barracks in Illesheim, and U.S. Army Garrison Wiesbaden Schools

Alexander M. Zhivov, David M. Underwood, John L. Vavrin, Alfred Woody, Curt Bjork, James Newman, Erja Reinkinen, Timo Husu, Michael Schmidt, Manfred Klassek, Gunther Claus, Martin Zinsser, Reijo Vaisanen, Timo Kauppinen, Heike Erhorn-Kluttig, Hans Erhorn, and Anna Staudt

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Final Report

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Washington, DC 20314-1000

Abstract: An energy and process optimization assessment (EPOA) study was conducted at selected U.S. Army installations in Germany and at two U.S. Army Garrison Wiesbaden schools to identify potential for energy conservation at those locations. The study identified energy conservation, process optimization, and environmental improvement opportunities that could significantly reduce operating costs and improve the installations' mission readiness and competitive position. Eighty five energy conservation measures (ECMS) were identified, most of which were quantified economically; if implemented, these ECMS would reduce annual electrical energy consumption by approximately 2412 MWH, thermal heating consumption by 17277 MWH, and total operating costs by approximately $1.4 million/yr. Implementation of all these ECMS would cost approximately $9.7 million and would yield an average simple payback of 7.2 yrs. The study recommends that these potential cost savings be aggressively pursued with an program of energy and process optimization. A separate level I EPOA study of the industrial complex at the Germersheim DDDE and a Level II EPOA study at the flight simulator building in Illesheim were also recommended, since these locations both show potential for significant reductions in energy use and operating cost, and for improvement in worker productivity.

Executive Summary

Summary

An Energy and Process Optimization Assessment (EPOA) study was conducted at selected U.S. Army Installations, which included Keiserslautern Army Depot, Piermasens Army Depot, Katterbach Kaserne, Storck Barracks in Illesheim. Additionally, a brief assessment visits were made to the U.S. Army Germersheim Army Depot and a warehouse complex Big-O at Defense Distribution Depot Europe (DDDE), and at the U.S. Army Garrison Grafenwoehr to identify potential for energy conservation at those locations. A separate energy assessment analysis of two U.S. Army Garrison Wiesbaden Schools using energy concept adviser (ECA) developed by the IEA ECBCS Programme Annex 36 was performed at later time and its results are included in this report.

Eighty five Energy Conservation Measures (ECMs) addressing Central Energy Plants and distribution systems, Building envelops, Compressed Air Systems, HVAC, Electrical and Lighting technologies were identified and most of them were quantified economically. If implemented, these ECMs would reduce annual electrical energy consumption by approximately 2412 MWh, thermal heating consumption by 17,277 MWh, and total operating costs (energy, maintenance and labor) by approximately $1.4 million/yr.

Implementation of these ECMs (Table E1) would cost approximately $9.7 million and would yield an average simple payback of 7.2 yrs. It is recommended that these potential cost savings be aggressively pursued with a program of energy and process optimization and that the 34 low cost/no risk measures be funded internally as soon as possible.

Implementation of 43 moderate cost/low risk ECMs with a higher investment requirements (between $20K and $1 million) will yield annual savings of $989,000, and will require $4.1 million in investments, which will yield a simple payback of 4.2 yrs. (Some of these complex ECMs may require SME support to provide 30 percent design.) These ECMs can be implemented either using central funding or third part financing mechanisms: Energy Savings Performance Contracts (ESPC) or Utility Energy Services Contracts (UESC).

The ECMs for the Wiesbaden Schools show a payback about 23 yrs; it is recommended that thee ECMs be implemented when other retrofit non-energy related projects are planned, or by using ESPC or UESC mechanisms.

This study recommends a separate Level I EPOA assessment of the industrial complex at the Germersheim DDDE and a Level II EPOA assessment at the flight simulator building in Illesheim, since both those locations have a potential to significantly reduce energy use and operating costs, and to improve worker productivity.

The 72 ECMs at Keiserslautern and Pirmasens AD, summarized in Table E2, would reduce electrical consumption by approximately 2,386 MWh, thermal heating consumption by 11,594 MWh, total operating costs (energy, maintenance and labor) by approximately $1.1 million/yr; these ECMs would cost $3.85 million and would yield an average simple payback of 3.5 yrs.

The 11 primarily HVAC-related ECMs at Katterbach and Illesheim (described in Chapter 5 and summarized in Table E1) would reduce thermal heating consumption by 1,117 MWh and operating costs by approximately $74,500/yr, would cost $481000, and would yield an average simple payback of 6.5 yrs.

Table E1. Summary of all ECMs.

ECM Category	Chapter	# ECMs	Electrical Savings MWh/yr	Electrical Savings $K/yr	Thermal Savings MWh/yr	Thermal Savings $K/yr	Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
Lighting - Kaiserslautern & Pirmasens	4.2	18	367	29.5	0	0	0	29.5	36.8	1.25
Building Envelope – Kaiserslautern	4.3	15			3,702	241	70	311	1,856	6
Compressed Air – Kaiserslautern	4.4	1	203	16				16	2	0.1
Electrical – Kaiserslautern	4.5	1	37	3				3	0	0.0
HVAC – Kaiserslautern	4.6	26	516	41	2745	250	117	408	1346	4.5
Building Envelope - Pirmasens	4.7	4	0	0	514	33		33	162	4.9
District Heating – Pirmasens	4.8	1			1,019	48		48	20	0.4
Electrical Pirmasens	4.9	1	25	2				2	0	0.0
HVAC – Pirmasens	4.10	5	122	10	2,625	172		182	335	1.8
HVAC-Ansbach area:– Katterbach and Illesheim	5.1	11			1117.3	74.5		74.5	481	6.45
Wiesbaden Schools	6	2	25.8	3.7	4565.2	225.5		229.2	5357.1	23.4
Total		*85*	*1296*	*105*	*16288*	*1044*	*187*	*1336*	*9596*	*7.2*

Table E2. Summary of all ECMs at Keiserslautern and Pirmasens AD.

ECM Category	Chapter	# ECMs	Electrical Savings		Thermal Savings		Additional Savings	Total Savings	Investment	Simple Payback
			MWh/yr	$K/yr	MWh/yr	$K/yr	$K/yr	$K/yr	$K	yrs
Lighting - Kaiserslautern & Pirmasens	4.2	18	367	29.5	0	0	0	29.5	36.8	1.25
Building Envelope – Kaiserslautern	4.3	15			3,702	241	70	311	1,856	6
Compressed Air – Kaiserslautern	4.4	1	203	16				16	2	0.1
Electrical – Kaiserslautern	4.5	1	37	3				3	0	0.0
HVAC – Kaiserslautern	4.6	26	1632.4	82.3	3734	275	116.6	475	1433.2	3
Building Envelope – Pirmasens	4.7	4	0	0	514	33		33	162	4.9
District Heating – Pirmasens	4.8	1			1,019	48		48	20	0.4
Electrical Pirmasens	4.9	1	25	2				2	0	0.0
HVAC – Pirmasens	4.10	5	122	10	2,625	172		182	335	1.8
Total		72	2386	142.8	11,594	494	186.6	1099	3845	3.5

Energy conservation concepts developed for the two Wiesbaden Schools (described in Chapter 6 and summarized in Table E1) would reduce electrical consumption by approximately 25.8 Mwh, thermal heating consumption by 4565 MWh, and total operating costs by approximately $229,000/yr; these concepts would cost $5.4 million and yield an average simple payback of 23.4 yrs.

Recommendations

The Level I analysis of multiple complex systems conducted during the EPOA are not intended to be (nor should they be) precise. The quantity and quality of the systems improvement identified suggests that sufficient potential exists. It is recommended that these potential cost savings be aggressively pursued. It is also recommended that the low cost/no risk (so-called “slam dunk”) ECMs that can typically be implemented quickly (summarized in Table E3) be funded internally and implemented as soon as possible. All 34 ECMs in this table require an investment of $95K and would yield an average simple payback of about 0.8 yr. Together they have potential to save $118K/yr. All lighting projects under this category can be implemented as a one project.

Table E4 summarizes 43 moderate cost/low risk ECMs with a higher investment requirements (between $20K and $1 million). If implemented, these ECMs will together result in annual savings of $989 thousand, will require $4.1 million in investments, and will yield a simple payback of 4.2 yrs. (Some of these complex ECMs may require SME support to provide 30% design.) All projects which propose replacement of unit and other warm air heating systems with hydronic radiant panels are recommended to be packaged and implemented as a one project.

Table E3. Summary of low-cost/no-risk ECMs.

ECM	ECM Description	Electrical Savings		Thermal Savings		Total Savings $K/yr	Investment $K	Simple Payback yrs
		MWh/yr	$K/yr	MWh/yr	$K/yr			
LI1-LI18	Kaiserslautern and Pirmasens Lighting ECMs	367	29.5	0	0	29.5	36.8	1.25
BE6	Repair door seals, building 2226			9.7	0.63	0.63	2	3.2
BE8	Place insulated panel in unused door areas in building 2371			51.8	3.4	3.4	7.2	2.1
BE9	Repair damaged doors in building 2371			9.7	0.6	0.6	1	1.6
BE14	Repair door seals, building 2370			9.6	0.6	0.6	2	3.2
BE17	Close Opening Above Crane Using Brushes and Rubber Strips, Building 4000			19	1.2	1.2	1.6	1.3
BE18	Close Openings in Carpenter Storage Room, Building 4000			10	0.6	0.6	1	1.6
CA1	Turn Off Air Compressors on Weekends and Nights Building 2224	203	16.2			16.2	1.5	0.1
EL1	Switch off Computers When Not In Use — Bldg 2233	36.8	2.9			2.9	0	0
EL2	Switch off Computers When Not In Use Building 4000	24.5	2			2	0	0
HV4	Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers 1 to 3			36.3	2.4	2.4	12	5.1
HV6	Reduce Excessive Air Use in Welding and Vehicle Exhaust Building 2233	46.4	3.7			3.7	7.5	2
HV13	Place Thermostat Controls Away From Occupants. Improved Control For Air Heaters	105	8.4			8.4	0.2	0.02
HV21	Have Heating Utility Turn off Heat to Buildings when not Warranted							Immediate
HV22	Use Heat from Generator Test for Building Heat, Building 2362			78	5.1	5.1	15	3
HV24	Provide Better Controls Of H&V In Building 2371	365	29.2	600		29.2		0
HV25	Insulate Heating System Components-Building 2371							< 2 yrs
HV26	Provide Temperature Control Of Unit Heaters In Building 2281		0	180	11.7	11.7	7	0.6
Total 36ECMs		1147.7	91.9	1004.1	26.23	118.13	94.8	0.8

All moderate cost ECMs can be implemented either using central funding or third party financing mechanism (e.g., Energy Savings Performance Contracts [ESPC] or Utility Energy Services Contracts [UESC]). It is also recommended that the energy projects at Wiesbaden schools (WS-1 and WS-2) be implemented together with other planned retrofit non-energy related projects, or by using ESPC or UESC mechanisms.

Table E4. Summary of moderate cost/low risk ECMs.

ECM	ECM Description	Electrical Savings MWh/yr	Electrical Savings $K/yr	Thermal Savings MWh/yr	Thermal Savings $K/yr	Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
BE1	Use transparent plastic panels behind glass sash, building 2233			2569	167		167	1052	6.3
BE2	a. Reduce solar heat load by use of conventional solar[1] film OR					70	70	280	4
BE3	Add vestibule on west side door of building 2233			137	8.9		8.9	105	11.8
BE5	Provide insulated panels for door openings in building 2222			28.3	1.84		1.84	16.8	9.1
BE7	Add vestibule on west side of building going-up ramp in building 2371			145	9.4		9.4	50.4	5.3
BE10	Insulate north wall bldg 2371			49.8	3.2		3.2	22.5	7
BE11	Use transparent plastic panels behind glass windows building 2281			158	10.3		10.3	64.7	6.3
BE12	Use transparent plastic panels to replace roof skylights building 2281			118	7.7		7.7	70.4	9.2
BE13	Repair and insulate roof building 2281			372	24.2		24.2	149.6	6.2
BE15	Insulate roof in maintenance building #2226			44.8	2.9		2.9	32.8	11.3
BE16	Install Drop Ceiling in Certain Spaces, Building 4000			22	1.4		1.4	32.7	23.4
BE19	Add Wall Insulation, Building 4171			464	30.2		30.2	127	4.2
HV2	Install Exhaust Fans To Ventilate Building 2233					116.64	116.6	65	0.6
HV3	Install Destratification Fans Recover Heat in Upper Strata – Building 2233			700	45.5		45.5	40	0.9
HV5	Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2233,			6.06	98.5		98.5	459.9	4.7
HV7	Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,			95	6.2		6.2	33.95	5.5
HV8	Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,			24	15.6		15.6	97.9	6.3
HV9	Recirculate Exhaust Air Back into Booth During Drying Operations, Building 2225			59	3.8		3.8	20	5.2
HV10	Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2238			185.6	12.06		12.06	98.42	8.2
HV11	Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2239			283.5	18.43		18.43	145.5	7.9
HV14[3]	Increase Ventilation to Reduce Solvent Fumes in Space-Building 2222							40	
HV15	Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop Building 2225			76.5	4.4		4.4	31.75	7.2
HV16[4]	Provide Heaters over Doors on South Side-Building 2226							100	
HV17	Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2226			120	7.8		7.8	54.5	7

ECM	ECM Description	Electrical Savings		Thermal Savings		Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
		MWh/yr	$K/yr	MWh/yr	$K/yr				
HV18	Separate the Building Heating System from the Boiler and Connect the Building to District Heating System at Apprentice Shop, Building # 2364			~25%	~25%				< 5 yrs
HV19	Replace Warm Air Heaters with Hot Water Radiant Panels in Apprentice Shop, Building # 2363			75	4.9		4.9	39.3	8.1
HV20	Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop, Building # 2372			190	11.4		11.4	53.25	4.7
HV23	Provide Door Heater at Door on East Side of Building 2371			36	2.3		2.3	25	10.7
CEP1	Turn Off District Heating to Buildings In Summer			1019	47.9		47.9	20	0.4
HV27	Improve HVAC System Controls Building 4000		0	1000	65		65	150	2.3
HV28	Install Door Heater, Building 4155			13	0.8		0.8	25	29.6
HV29	Improve H&V System Controls & Air Movement In Building 4171, Pirmasens	105	8.4		26		34.4	20	0.6
HV30	Install Economizers, Building 4111, Pirmasens		0	799.2	40		40	90	2.3
HV32	Install Measurement Equipment, Building 4111	16.5	1.3	812.5	40.6		41.9	50	1.2
HV33[1]	Heating system improvement in Commissary at Katterbach Building 5805		-	45.3	3.7		3.7	22	5.9
HV35	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5801			149	8.94		8.94	59.75	6.7
HV36	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5802			90	5.9		5.9	40	6.7
HV37	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5508	-		100	6		6	40	6.7
HV38	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5807		-	107	6.42		6.42	50	7.8
HV39	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5806	-	-	80	4.8		4.8	62	12.9
HV40	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6500	-	-	269	16.14	-	16.14	79	4.9
HV41	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6501	-	-	142	8.52	-	8.52	45	5.3
HV42	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6502	-	-	235	14.1	-	14.1	83	5.9
Total 43 ECMs				10720	793	187	989	4,144	4.2

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Preface

This study was conducted for the Installation Management Agency Europe under Project Requisition No. 127396, Activity A1020, "Annex 46 Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)," via Military Interdepartmental Purchase Request (MIPR) MIPR6CCERB1011. The technical monitor was David Yacoub, IMA Europe Region, Engineer Division.

The work was managed and executed by the Energy Branch (CF-E) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL principal investigators were Dr. Alexander Zhivov, John L. Vavrin, and David M. Underwood. Appreciation is owed to Dieter Geppert, Rudolf Gmelch, Helmut Wieder, Kenneth Holden, Ron Boese, Patrick Hutchins, Mark Love, Eric Wilking, Kent Carson, Paul Lindeman, Joseph Shultz, Guilliermo Rivera, Ron Harris, Darius Nickolson, Franz Schwartz, Karl Kirch, and Peter Hartman. Major contributors to the study were Al Woody, Jim Newman, Erja Reinikainen, Manfred Klassek, Curt Bjork, Gunther Claus, Timo Husu, Michael Schmidt, Reijo Vaisanen, Martin Zinsser, and Timo Kauppinen. Dr. Thomas J. Hartranft is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Martin J. Savoie. The Director of CERL is Dr. Ilker Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Richard B. Jenkins, and the Director of ERDC is Dr. James R. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
British thermal units (International Table)	1,055.056	joules
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
foot-pounds force	1.355818	joules
gallons (U.S. liquid)	3.785412 E-03	cubic meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
inch-pounds (force)	0.1129848	newton meters
miles (U.S. statute)	1,609.347	meters
ounces (mass)	0.02834952	kilograms
ounces (U.S. fluid)	2.957353 E-05	cubic meters
pounds (force)	4.448222	newtons
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per inch	175.1268	newtons per meter
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
quarts (U.S. liquid)	9.463529 E-04	cubic meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

1.1 Background

An Energy and Process Optimization Assessment (EPOA) was conducted at several U.S. Army locations in Germany, which included Kaiserlautern Army Depot (KAD), Pirmasens Army Depot (PAD), Ansbach area (Katterbach Kaserne and Storck Barracks in Illesheim), and at the U.S. Army Garrison Wiesbaden Schools).

Kaiserslautern is 80 miles southwest of Frankfurt, Germany and 295 miles northeast of Paris, France. The Kaiserslautern Military Community is the largest military community outside the continental United States, and is a combined community consisting of Army and Air Force components. Several U.S. Army Europe, or USAREUR, installations are scattered throughout the KMC. The Army installations stretch from the east side of Kaiserslautern, west to Miesau and south to Pirmasens. There are eight different Army installations comprising the KMC: Kleber Kaserne (Northeastern Kaiserslautern) Daener Kaserne (Northeastern Kaiserslautern) Panzer Kaserne (Northeastern Kaiserslautern) Landstuhl Regional Medical Center (Landstuhl) Rhine Ordnance Barracks (Western Kaiserslautern) Pulaski Barracks (Western Kaiserslautern) U.S. Materiel Command Center Europe/226th Med Bn (remote site at Pirmasens) Vogelweh (Western Kaiserslautern). Kaiserslautern Army Depot has 191 buildings (total area of 2.8. million sq ft). Parmasens has 73 buildings (1.1. million sq ft)

Pirmasens. The U.S. Army Medical Materiel Center, Europe (USAMMCE), in Pirmasens, Germany was established to deliver class VIII (medical materiel) to forces deployed to Camp Able Sentry, Macedonia, and, later, to Camp Bondsteel, Kosovo. USAMMCE had provided medical supply support indirectly to units deployed to Macedonia as part of the United Nations Protection Force since 1993. Since 1999 USAMMCE was tasked to establish a direct ground LOC to Camp Able Sentry for commercial and military trucks.

The Maintenance Activity – Pirmasens (MAP) has over 50 yrs experience in the repair and overhaul of electronic gear, shelter systems, heating and air conditioning, power generation and selected automotive components for the U.S. Army, NATO, and other U.S. agencies.

Several Army installations in Ansbach include Shipton Kaserne, home to 6th Bn., 52nd Air Defense Artillery, Katterbach Kaserne, where the 1st Infantry Division's 4th Combat Aviation Brigade resides, Bismarck Kaserne where the post exchange, theater, and community club are located, and Barton Barracks, home to USAG Ansbach. Storck Barracks in Illesheim, located approximately 30 kilometers (18 miles) from Ansbach, are home to V Corps' 11th Aviation Regiment.

Elementary and the Middle School Hainerberg surveyed as a part of this project, are a part of the U.S. Army Garrison Wiesbaden, which includes Wiesbaden Army Airfield, Anderson Barracks in Dexheim and McCully Barracks in Wackernheim.

Wiesbaden Army Airfield serves as the headquarters installation for U.S. Army Garrison Wiesbaden, 1st Armored Division and 3rd Corps Support Command. Located 15 minutes away from Frankfurt International Airport, the Wiesbaden military community is host to several tenant units including the Corps of Engineers, Defense Logistics Agency, Wiesbaden Contracting Center, Army and Air Force Exchange Service, United Services Organization, Department of Defense Dependent Schools, Army Audit Agency, Defense Contract Management Command-Southern Europe, European Technical Center, Science and Technology Center and American Forces Network-Hessen. Anderson Barracks in Dexheim is located approximately 20 miles south of Wiesbaden Army Airfield and is the home of the 123rd Main Support Battalion, 1st Armored Division. McCully Barracks is home to the 501st Military Intelligence Battalion in Wackernheim.

1.2 Objectives

The objectives of this study were to identify energy inefficiencies and wastes at the selected U.S. Army Installations in Germany and propose energy related projects that could enable the installations to better meet the energy reduction requirements mandated by Executive Order 13423 and EPACT 2005.

1.3 Approach

This study was conducted by a team of government and private sector subject matter experts and researchers from the United States: Alexander Zhivov, David Underwood, and John Vavrin (CERL), Al Woody (Ventilation/Energy Applications, PLLC), Jim Newman (Newman Consulting Group, LLC), Finland: Erja Reinikainen (Granlund OY), Timo Kauppinen, VTT, Timo Husu, Motiva OY, Reijo Vaisanen (Fatman OY), Sweden: Curt Bjork (Curt Bjork Fastighet & Konsult AB) and Germany: Michael Schmidt, Martin, Zinsser, Manfred Klassek and Gunther Claus (University of Stuttgart, IGE), Heike Erhorn-Kluttig, Hans Erhorn and Anna Staudt (Fraunhofer IBP). The study was conducted using Energy Assessment Protocol developed by CERL in collaboration with a team of government, institutional, and private sector parties as a part of the IEA ECBCS Programme Annex 46 "Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)," accessible through URL:

https://kd.erdc.usace.army.mil/projects/ecbcs/

Energy Assessment of two schools in Wiesbaden was conducted using IEA Annex 36 Energy Concept Adviser, accessible through URL:

www.annex36.com

1.4 Scope

This Level I energy assessment evaluated warehouses and industrial production processes and buildings at Kaiserslautern AD and Pirmasens Army Depot, Wiesbaden Schools, and non-industrial facilities at the U.S. Army installations in Ansbach area (Katterbach and Illesheim): Barracks, Operations and Admin Facilities, Training Facilities, warehouses, motor pools, hangars, commissary, schools) and addressed areas related to the building envelope, ventilation, AC and heating systems, process ventilation, compressed air systems, energy plant and distribution systems, lighting, etc.

1.5 Mode of Technology Transfer

The results of this work will be presented to installations and IMCOM for their consideration in pursuing implementation and funding and for the follow-on Level II assessments in the identified areas. The results of this work are anticipated to contribute to an enhanced awareness within the

Installation Management Command (IMCOM), the U.S. Army Corps of Engineers and its districts, and other Army organizations of opportunities to improve the overall energy efficiency of Army installations. Plans are to disseminate this information through workshops, presentations, and professional industrial energy technology conferences. This report will also be made accessible through the World Wide Web (WWW) at URL: http://www.cecer.army.mil

2 CERL's Energy Assessment Methodology

2.1 The Energy Audit

A variety of energy and industrial assessment methodologies, protocols, and guidelines have been developed over the past years to improve energy efficiency of both private and government facilities. These audit tools have different emphasis and thoroughness, which depend on the audit objectives and on the available human and financial resources.

The study was conducted using Energy Assessment Protocol developed by CERL in collaboration with a team of government, institutional, and private sector parties as a part of the IEA ECBCS Programme Annex 46 "Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)." The protocol is designed to assist installation energy managers and REMs to develop energy conservation projects (self-help for energy managers). With a group of American and international technical experts, ERDC/CERL has previously used this methodology for energy assessments conducted in 2003 – 2006 at Rock Island Arsenal, TYAD, SIAD and CCAD, Fort Carson, Fort Leonard Wood, Fort Stewart, Fort Myer, and Fort Polk.

The Energy Assessment Protocol addresses technical and non-technical organizational capabilities required to make a successful assessment geared to identifying energy and other operating costs reduction measures without adversely impacting Indoor Air Quality, product quality, or (in the case of repair facilities) safety and morale.

A critical element for energy assessment is a capability to apply a "holistic" approach to the energy sources and sinks in the audited target (installation, building, system, and their elements). The holistic approach suggested by the protocol includes the analysis of opportunities related to the energy generation process and distribution systems, building envelope, lighting, internal loads, HVAC, and other mechanical and energy systems. A useful way of visualizing the energy flows within a facility or process is the Sankey diagram, as shown in Figures 1 and 2.

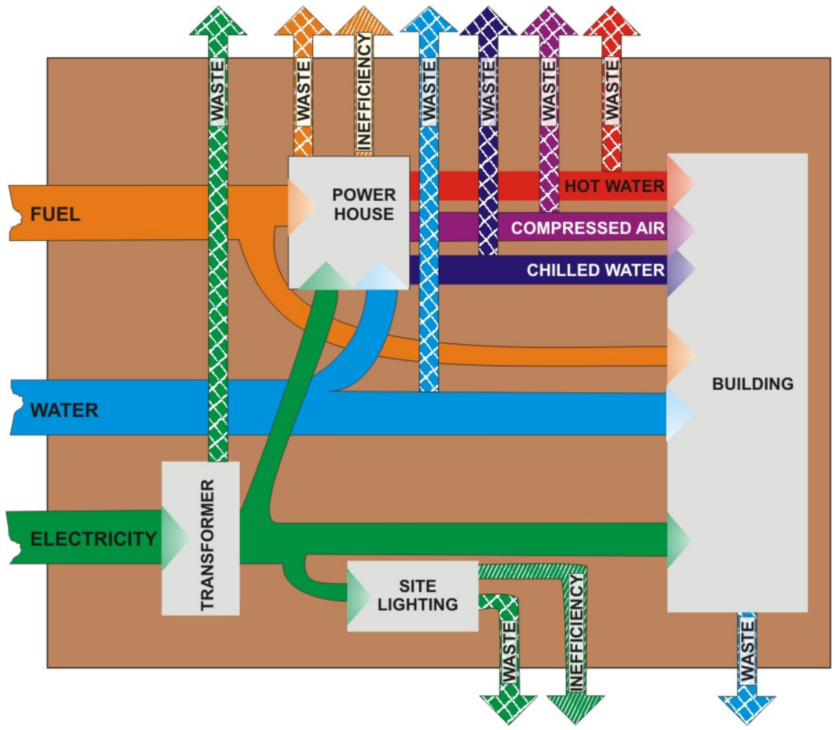


Figure 1. Example Sankey diagram of energy usage, waste, and inefficiencies for an Army installation.

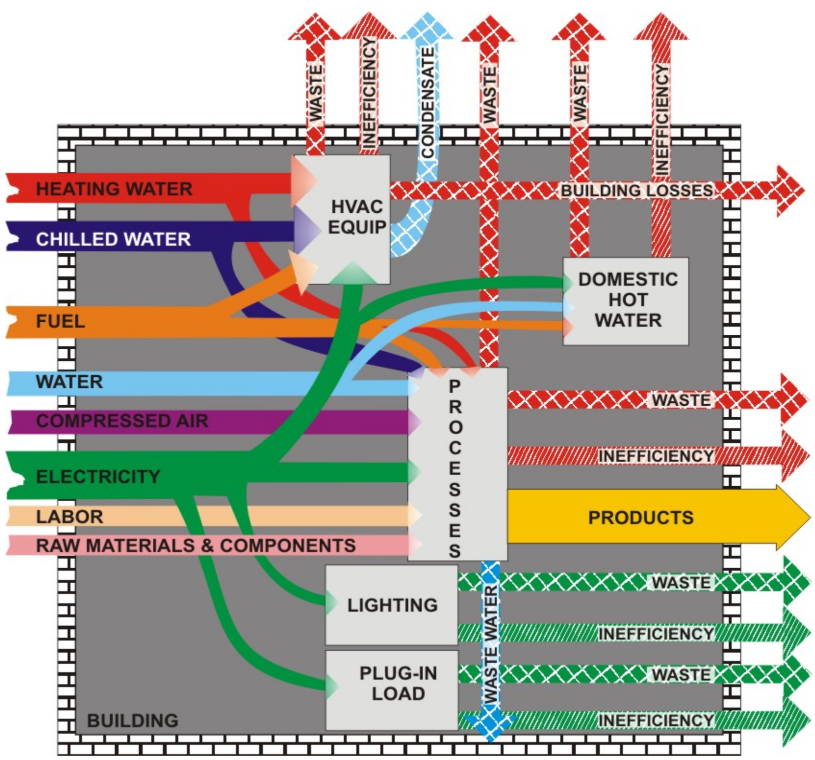


Figure 2. Example Sankey diagram of energy usage, waste, and inefficiencies for a building with production process.

The Protocol addresses several different scopes (building stock, individual building, system, and component) and levels of assessment. It distinguishes between the pre-assessment phase (Level 0: selection of objects for Energy Assessments and required composition of the audit team) and three levels of energy audits with differing degrees of rigor. Each of these three levels may be implemented in different ways: simplified or more detailed assessments, depending on the availability of energy consumption information and other data.

During the selection phase, one can choose from a building stock those facilities that have the most promising energy saving potential. Similarly, one can select from a specific building the systems to be audited or, from a system, the components to be considered for more detailed analysis. The scope and depth of the assessments differ in their objectives, methodologies, procedures, required instrumentation, and approximate duration (Figure 1).

A *Level I* audit (qualitative analysis) is a preliminary energy and process optimization opportunity analysis consisting primarily of a walk-through review to analyze and benchmark existing documents and consumption figures. The Level I audit takes from 2 to 5 days, and identifies the bottom-line dollar potential of energy conservation and process improvements.

No engineering measurements using test instrumentation are made. If the consumption figures are not available (e.g., due to the absence of metering), which is typical for many industrial facilities and manufacturing processes, the Level I audit can be based on analyses and estimates by experienced auditors. A Level I audit would normally recommend that the installation perform some metering, which could be followed by a Level II audit to verify the Level I assumptions, and to more fully develop the ideas from the Level I screening analysis.

A *Level II* audit (quantitative analysis) includes an analysis geared towards funds appropriation; this analysis uses calculated savings and partial instrumentation measurements with a cursory level of analysis. The Level II study typically takes 5 to 10 times the effort of a Level I, and could be accomplished over a 2- to 6-month period, depending on the scope of the effort.

The Level II effort includes an in-depth analysis in which the most crucial assumptions are verified. The end product will be a group of "appropriation grade" energy and process improvement projects for funding and implementation.

Finally, the *Level III* audit (continuous commissioning) is a detailed engineering analysis with implementation, performance measurement and verification (M&V) assessment, and fully instrumented diagnostic measurements (long term measurements). This level takes 3 to 18 months to accomplish. For ESPC projects, the *Level III* audit is prolonged until the end of the contract to guarantee that all installed systems and their components operate correctly over their useful lifetimes.

2.2 Keys to a Successful Audit

The key elements that guarantee success of the Energy Assessment are:

- Involvement of key facility personnel and their on-site contractors who know what the major problems are, where they are, and have already thought of many potential solutions;
- The facility personnel's sense of "ownership" of the ideas that encourages a commitment to successful implementation; and
- A focus on site-specific, critical cost issues. If solved, the greatest possible economic contribution to a facility's bottom line will be realized. Major potential cost issues can include: facility utilization (bottlenecks), mission, labor (productivity, planning and scheduling), energy (steam, electricity, compressed air), waste (air, water, solid, hazardous), equipment (outdated or state-of-the-art).

From a strictly cost perspective, process capacity and labor utilization/productivity and soldiers' well-being can be far more significant than energy and environmental concerns. All of these issues, however, must be considered together to accomplish the facility's mission in the most efficient and cost-effective way.

2.3 Requirements to an Energy and Process Auditing Team

Expertise in energy auditing is not an isolated set of skills, methods, or procedures; it requires a combination of skills and procedures from different fields. However, an energy and process audit requires a specific talent for putting together existing ways and procedures to show the overall energy performance of a building and the processes it houses, and how the energy performance of that building can be improved. A well grounded energy and process audit team should have expertise in the fields of heating, ventilating, and air-conditioning (HVAC), structural engineering, electrical and automation engineering and, of course, a good understanding of production processes.

Most of the knowledge necessary for energy audit is a part of already existing expertise. Designers, consultants, contractors, and material and equipment suppliers should be familiar with the energy performance of the *specific* field in which they are experts. Structural designers and consultants should be familiar with heat losses through the building shell and what insulation should be added. Heating and ventilation engineers should be familiar with the energy performance of heating, ventilation, compressed air, and heat recovery systems. Designers of electrical systems should know energy performance of different motors, VFD drives, and lighting systems. An industrial process and energy audit requires knowledge of process engineers specialized in certain processes.

Critical to any energy and process audit team member is the ability to apply a “holistic” approach to the energy sources and sinks in the audited target (installation, building, system, or their elements), and the ability to “step outside the box.” This ability presumes a thorough understanding of the processes performed in the audited building, and of the needs of the end users. For this reason, the end users themselves are important members of the team. It is critical for management, production, operations and maintenance (O&M) staff, energy managers, and on-site contractors to “buy-in” to the implementation by participating in the process, sharing their knowledge and expertise, gathering information, and developing ideas.

2.4 Preliminary Data Collection

Data collection prior to going to site will save time and money, and will also foster a partnership between the energy assessment team and the end-users. Early collection of the following data is desirable:

- master plan, building drawings, information on different shop areas, volume, occupancy patterns, typical building/shop usage, process lay-outs
- production hours for different areas/ shops, number of workers in each shift
- operation time for different processes
- any information on existing ventilation systems (layouts, airflows, con-trols, operation instructions)
- information on compressed air systems, boiler and chilled water plants, central child water and hot water/steam distribution systems
- heat and power prices (per unit)
- available information on energy use in recent years (electricity, oil, gas, etc.), site energy records of metered/sub-metered energy consumption, statistical data from the utility or/and bills, regarding electricity, oil, gas etc.
- total energy costs in recent years
- projected energy price increase (to be used in this project)
- key information related to production (number of units produced, use of raw materials, etc.) in different areas (past and the best estimates for the near and long-term future)
- recently completed energy improvement measures and results
- requirement to indoor air quality and thermal conditions in shops
- permits for exhaust air systems
- reports on recent studies (including ESCO proposals).

3 EPOA at Selected U.S. Army Installations in Germany

3.1 Project Planning and Schedule

Table 1 lists the assessment team and its organization. The energy audit took place over a 12-day period between Monday, 28 May and Thursday, 7 June 2006. Table 2 shows how the 12-day assessment process was organized by time, activities, and location to ensure that all of the critical areas in the scope of work were covered and that the process of the information collection, brainstorming sessions, and briefings to the management were built in to the busy personnel schedules. Table 2 lists sub teams assigned to the different process and energy system areas. In addition, An ERDC researcher made a brief assessment visits to the Germersheim Army Depot Complex Big-O at Defense Distribution Depot, Europe (DDDE) and to the U.S. Army Garrison Grafenwoehr (see Appendix A). In August 2006, a team from Fraunhofer Institute of Building Physics (Stuttgart) did a separate energy assessment analysis of two U.S. Army Garrison Wiesbaden schools using Energy Concept Advisor (ECA) software developed by International Energy Agency ECBCS Programme, Annex 36.

The formal out-briefing to the IMA Europe Region was conducted on 9 June 2006.

Table 1. Assessment team.

Teams Assignments				
	Kaiserslautern		Ansbach/Illisheim	
Leader	Al Woody	Al Woody	Timo Husu	Alexander Zhivov
Members	Jim Newman	Jim Newman	Alexander Zhivov	
	Erja Reinikainen	Dave Underwood	Michael Schmidt	
	Dave Underwood		Reijo Vaisanen	
	Manfred Klassek		Martin Zinsser	
	Curt Bjork		Timo Kauppinen	
	Gunther Claus			
Location	**Pirmasens**	**KAD**	**Ansbach Area**	**Ansbach Area**
Facilities, in no particular order	**4000 (Maint Shop)**	2281 (W)	**Ansbach Katterbach**	**Illesheim**
	4155 (Admin)	2371 (Ship/Rec)	5508 (H)	6500 (H)

Teams Assignments				
	Kaiserslautern		Ansbach/Illisheim	
(building number) (bold in priority)	4111(Energy Plt)	2239 (W)	5801 (H)	6501 (H)
	4172 (W)	2238 (W)	5802 (H)	6502 (H)
		2213 (W)	5806 (H)	6658(Sim)
		2219 (W)	5807 (H)	6503 (VMS)
		2370 (W)	5924 (HS)	6633 (VMS)
Facilities, in no particular order (building number) (bold in priority)		2213(W)	5805 (Gym)	
		2219 (W)	PX	Shipton
		2363 (VMS)		8007 (VMS)
		2362 (Gen repair)	Ansbach Bismark	8012 (VMS)
		2226 (Maint Shop)	5903 (VMS)	
		2225 (Maint Shop)	5904 (VMS)	Barton
		2222 (Maint Shop)	5905 (VMS)	5261 (VMS)
		2233 (Maint Shop)	5906 (VMS)	5263 (VMS)
		2364 (Energy Plt)		5264 (VMS)

Table 2. Twelve-day assessment process.

Timeline												
Kaiserslautern Military Community												
Energy Showcase												
29 May - 9 June 2006												
Types of Facilities	Names (Leaders in Bold)	Dates										
		30-May Tuesday	31-May Wednesday	1-Jun Thursday	2-Jun Friday	3-Jun Saturday	4-Jun Sunday	5-Jun Monday	6-Jun Tuesday	7-Jun Wednesday	8-Jun Thursday	9-Jun Friday
Team Kaiserslautern												
	Al Woody	Kaiserslautern Military Community					Personal Time	Kaiserslautern Military Community				Depart for Home
	D. Underwood											
	Jim Newman											
	Curt Bjork											
	Erja Reinikainen											
	Manfred Klassek											
	Gunther Claus											
Team Ansbach/Illisheim												
	Timo Husu	Ansbach & Illisheim Area					Personal Time					
	Alexander Zhivov							Ansbach & Illisheim Area				
	Martin Zinsser											
	Reijo Vaisanen											
	Timo Kauppinen											
	Manfred Klassek							Ansbach & Illisheim Area				
	Michael Schmidt	Ansbach & Illisheim Area										
Schools												
	Hans Erhorn		Wiesbaden Schools			Change dates - Resend their request to the new school administrators						
	Heike Erhorn		HS, Middle and Grade									

3.2 Energy Supply, Consumption, and Costs

In 2005, U.S. Garrison Kaiserslautern used 72,832 MWh of electricity at a cost of $4,177,588 and had a maximum demand of 14,382 KW. Also, 408,036 MBTU of district heat was used at a cost of $8,850,812 (Table 3).

Table 3. Energy supply, consumption, and costs, Garrison Kaiserslautern (2005).

USA Garrison Kaiserslautern 2005						
		Electricity			District Heat	
	MWH	MMBtu	KW Max	Cost $	MBTU	Cost $
Jan	6,924	23,625	14,382	383,750	62,100	1,008,093
Feb	6,484	22,123	14,098	372,695	60,518	969,265
Mar	6,469	22,072	14,265	368,767	50,260	896,356
Apr	6,226	21,243	12,912	368,394	33,014	747,863
May	5,549	18,933	12,276	337,660	23,133	657,312
Jun	5,608	19,134	13,185	340,076	8,251	483,719
Jul	5,553	18,947	12,523	343,873	6,926	472,182
Aug	5,688	19,407	12,327	344,759	6,586	474,622
Sep	5,707	19,472	12,260	365,244	12,704	543,960
Oct	5,868	20,022	12,853	295,429	34,223	747,250
Nov	6,166	21,038	13,624	312,208	49,899	887,719
Dec	6,590	22,485	12,876	344,733	60,422	962,471
Total	72,832	248,503		4,177,588	408,036	$ 8,850,812

With the exception of heating oil, the costs were the same for the other installations. Pirmasens cost for heating oil was $50/MWHth.

4 Assessment Results

This Chapter includes the assessment results for which both cost and savings estimates were made. With the exception of lighting, the ECMs are organized first by the location (Kaiserslautern, Pirmasans, Ansbach area, Wiesbaden Schools), and then by system type as listed:

1. Building Envelope (BE)
2. Compressed Air (CA)
3. Central Energy Plant (CEP)
4. Electrical (EL)
5. HVAC (HV).

Appendix B to this report summarizes all ECMs.

4.1 Energy Costs Used To Determine Results

The energy costs used to determine results were:

- Heating: $65/MWh*
- Electricity: $80/MWh (Expected future costs)
- Fuel Oil: $51/MWh.

4.2 Kaiserslautern and Pirmasens Lighting (LI)

Table 4 lists the facilities with potential lighting ECMs.

Table 4. Facilities with potential lighting ECMs.

Facility	ECM	System Category
2233, 2281	Add daylight sensors to switch off lighting in work areas where daylight is available (skylights)	LI
2233, 2371, 2225, 4000	Switch off unnecessary lighting by adding occupancy sensors in areas where there is no activity	LI
2370, 2371, 2213, 4171	Change lamp type to more energy efficient	LI
4155 and others	Install energy efficient lighting in renovations	LI
all buildings	Install energy efficient LED exit-lights in renovations	LI
4171	Paint ceiling white to improve lighting conditions	LI

* $1.3 = 1 €.

4.2.1 LI #1: Install Energy Efficient LED Exit Lights All Buildings

4.2.1.1 Existing Conditions

Most buildings have ordinary fluorescent exit lights. The tube type is usually an 11W fluorescent tube. There are an estimated 250-300 exit lights in the buildings.

4.2.1.2 Solution

To improve energy efficiency of exit-lights, LED-lights should be used.

Instead of 11W a LED-light has a power input of 4W. The life time of LED-lights is much longer than that of fluorescent tubes.

4.2.1.3 Savings

Savings are calculated as:

Savings per fixture = 24 hrs/day x 365 days/yr x 7W x 1MW/1,000,000W x $80 / MWHe = $4.90 / yr (3.77 €/yr)*

If all fixtures (estimated 270) are changed, the savings will be about $1325/yr.

4.2.1.4 Investment

An LED exit sign can cost between $30 and $250 in comparison to $20 and $100 for an incandescent and $125 and $200 for a fluorescent sign. Retrofit kits can be purchased to convert any exiting incandescent or fluorescent sign to an LED sign. The retrofit kit can cost $40, which includes all the necessary hardware for the conversion. Here a price difference of $40 (30 €)/fixture has been used.

4.2.1.5 Payback Calculation

The calculated payback will occur in:

Per fixture $40 / $4.90 / yr = 8.2 yrs

* $1.30 = 1 €.

The conclusion is that when the electrical system, lighting installation, or exit lighting in a building is renovated for technical reasons, more energy-efficient LED exit lighting fixtures should be installed.

4.2.2 LI #2: Install Occupancy Sensors To Turn Off Unnecessary Lighting—All buildings: Restrooms, Lunchrooms, etc.

4.2.2.1 Existing Conditions

In most cases the lighting in restrooms, locker rooms, and lunch rooms is on all day. Building 2233 is a typical example.

4.2.2.2 Solution

Install occupancy sensors in restrooms, lunch rooms, etc to turn off the lighting when the rooms are unoccupied. In most cases, the occupancy time is only 2 to 3 hrs/day.

4.2.2.3 Savings

Assuming that the lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day.

The lighting capacity to be controlled by the occupancy sensor is typically 200W to 400W per room. Here it is assumed that there are 20 rooms where occupancy control could be added. The total lighting capacity in these is about 6 kW. Savings are calculated as:

Savings = 7 hrs/day x 240 days/yr x 6 kW x 1MW/1000kW x $80 / MWh = $806 / yr (620 €/yr)

4.2.2.4 Investment

A rough cost estimate is $250 for the sensor and some wiring. In some cases (such as typical restrooms), the manual wall switch could be replaced by an occupancy sensing switch. Here a total cost of $5,000 (3,800 €) has been used to cover 20 rooms.

4.2.2.5 Payback Calculation

The calculated payback will occur in:

$5,000 / $806 / yr = 6.2 yrs

4.2.3 LI #3: Use Daylight Sensors To Turn Off Unnecessary Lighting Building 2233 Maintenance Area—2233 Main Hall

4.2.3.1 Existing Conditions

The main hall in Building 2233 has about 60 luminaires with 400W mercury vapor lamps. The total lighting capacity in the hall is about 26.4 kW including ballasts. There are windows and skylights to provide plenty of daylight. All lights were on even on a sunny day.

4.2.3.2 Solution

Add daylight sensor to switch off the lights when there is enough daylight.

When there is 7,500 to 10,000 lux outside, the lights (or part of the lights) can be switched off. The lux-level is 10,000 lux or more on sunny and partly cloudy days. Between February and October the outdoor lux level should be sufficient during the working hours to allow indoor lighting to be switched off.

4.2.3.3 Savings

Assuming that the lighting in the main hall can be switched off 60 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting is needed more in winter time, during summer months the lights can be off all day. Savings are calculated as:

Savings = 6 hrs/day x 240 days/yr x 26.4 kW x 1MW/1000kW x $80 / MWh = $3,041 / yr (2,952 €/yr)

4.2.3.4 Investment

One daylight sensor can control lighting in several rooms connected to the lighting power distribution. Connecting the sensor to the lighting power distribution may require some changes in the distribution boards, it is possible to control lights in zones or even by contactor. A rough cost estimate is $1,200 for the sensor and some wiring, not including major changes in distribution boards. Here a total cost of $2,500 (1900 €) has been used to cover changes in two lighting areas.

If the electrical installation in Building 2233 is renovated, daylight control should be included.

4.2.3.5 Payback Calculation

The calculated payback will occur in:

$2,500 / $3,041 / yr = 0.8 yrs

4.2.4 LI #4: Use Daylight Sensors To Turn Off Unnecessary Lighting, Building 2233—Engine Repair and Other Areas on the North side

This was separated from the main hall lighting because here the task lighting will remain on whereas in the main hall all lighting switches off by daylight sensor.

4.2.4.1 Existing Conditions

The engine repair workshop area has a very high fluorescent task lighting capacity at about 2m height above the work areas. In addition to this there is general lighting in the hall with a mercury vapor lamp capacity of about 8 kW (20 fixtures). There are other areas on the North side of the building where the lighting installation is similar. The total amount of 400W mercury vapor lamps is about 50 (22 kW including ballast). There are windows on the North side of the building to provide some daylight. All lights were on even on a sunny day.

4.2.4.2 Solution

Add daylight sensor to switch off the mercury vapor lamps when there is enough daylight. The task lights are on during working hours.

When the mercury vapor lamps are switched off by the daylight sensor they require a time to cool before they can be switched on again. This is not an issue in the engine repair because there is enough task lighting on all the time.

4.2.4.3 Savings

Assuming that the mercury vapor lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting is needed more in winter time, during summer months the lights will be off all day. Savings are calculated as:

Savings = 7 hrs/day x 240 days/yr x 22 kW x 1MW/1000kW x $80 / MWh = $2,957 / yr (2,275 €/yr)

4.2.4.4 Investment

A rough cost estimate is $1,200 for the sensor and some wiring, not including major changes in distribution boards. Here a total cost of $2,500 (1,900 €) has been used to cover changes in two lighting areas.

If the electrical installation in Building 2233 is renovated, daylight control should be included.

4.2.4.5 Payback Calculation

The calculated payback will occur in:

$2,500 / $2,957 / yr = 0.9 yrs

4.2.5 LI #5: Install Daylight Sensors To Switch Off Unnecessary Lighting During Daylight Hours—Building 2281 Warehouse SAK

4.2.5.1 Existing Conditions

The building consists of three parts, the one at the West end has stacking shelves placed building lengthwise (E-W-direction) with seven aisles. The sections in the middle and east end have stack shelves placed crosswise with one main aisle in the middle of the building. There are luminaires between the shelves in all aisles. The luminaires have fluorescent 58W tubes. The total lighting capacity (including ballasts) is about 17.5 kW at the West end and 7.3 kW in the middle and east end. There are windows on the South side of the building and skylights to provide plenty of daylight. All lights were on even on a sunny day (for example, see Figure 2).

4.2.5.2 Solution

Add daylight sensor to switch off the fluorescent lighting between the shelves when there is enough daylight. The lights on the main aisle and the emergency lights should be on all the time for safety reasons. Some task lighting should remain on in the work area by the main door.

Figure 2. Luminaires between shelves in all aisles.

4.2.5.3 Savings

Assuming that the lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting is needed more in winter time, during summer months the lights can be off all day. The lighting capacity to be controlled by the daylight sensor is about 18 kW. Savings are calculated as:

Savings = 7 hrs/day x 240 days/yr x 18 kW x 1MW/1000kW x $80 / MWh = $2,419 / yr (1,861 €/yr)

4.2.5.4 Investment

A rough cost estimate is $1,200 for the sensor and some wiring, not including major changes in distribution boards. Here a total cost of $2,500 (1,900 €) has been used to cover changes in the two lighting areas.

4.2.5.5 Payback Calculation

The calculated payback will occur in:

$2,500 / $2,419 / yr = 0.9 yrs

4.2.6 LI #6: Install Daylight Sensors To Switch Off Unnecessary Lighting During Daylight Hours, Building 4000 Maintenance—Maintenance Area and Body Shop

4.2.6.1 Existing Conditions

The main maintenance hall in the middle of the building and the body shop on the east side of the building have large skylights facing North. The lighting installation consists of ceiling lights and some task lighting along the walls and in the vehicles under repair. The lighting in the main hall consists of four rows of luminaires with 400W mercury vapor lamps. The lights can be controlled in groups of four.

The total number of fixtures in the main hall is 48, having a total lighting capacity of 21.1 kW (including ballasts). During the site visit about 50 percent of the lights in the main hall were on.

The Body Shop has 28 fixtures with a total lighting capacity of 12.3 kW (including ballasts). During the site visit all the lights in the area hall were on.

4.2.6.2 Solution

Add daylight sensor to switch off the ceiling lighting when there is enough daylight (more than 7,500 or 10,000 lux). The task lighting should remain on in the work area.

A mercury vapor lamp takes some time to cool before it can be switched on again after switch-off. Rapid changes in daylight level are not very common.

4.2.6.3 Savings

Assuming that the lighting is partly switched off manually during the summer months, the saving is based on an assumption that the daylight control will switch the lights off 40 percent of the time, leading to an average saving of about 4 hrs/day. The lighting is needed more in winter time, during summer months the lights can be off all day. The lighting capacity to be controlled by the daylight sensor is about 33 kW. Savings are calculated as:

Savings = 4 hrs/day x 240 days/yr x 33 kW x 1MW/1000kW = 31.68MWh/yr

Savings = 31.68MWh/yr x $80 / MWh = $2,534 / yr (1,949 €/yr)

4.2.6.4 Investment

A rough cost estimate is $1,200 for the daylight sensor and some wiring, not including major changes in distribution boards. Here a total cost of $2,500 (1,900 €) has been used to cover changes in the two lighting areas.

4.2.6.5 Payback Calculation

The calculated payback will occur in:

$2,500 / $2,534 / yr = 1.0 yrs

4.2.7 LI #7: Install Daylight Sensors To Switch Off Unnecessary Lighting During Daylight Hours, Building 4000 Maintenance—Apprentice Workshop

4.2.7.1 Existing Conditions

The Apprentice workshop on the lower level of the building is situated on the North-West corner and has large windows to both directions. The lighting in the room consists of 42 fixtures with two 36W fluorescent tubes in each, having a total lighting capacity of 4.1 kW (including ballasts). During the site visit on a bright day all the lights were on.

4.2.7.2 Solution

Add daylight sensor to switch off 3/4 of the lighting when there is enough daylight. The 1/4 lighting should give enough task lighting in all conditions.

4.2.7.3 Savings

Assuming that the lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting is needed more in winter time, during summer months the lights can be off all day. The lighting capacity to be controlled by the daylight sensor is about 3.1 kW. Savings are calculated as:

Savings = 7 hrs/day x 240 days/yr x 3.1 kW x 1MW/1000kW = 5.21 MWh/yr

Savings = 5.21 MWh/yr x $80 / MWh = $417 / yr (321 €/yr)

4.2.7.4 Investment

A rough cost estimate is $1,200 for the daylight sensor and some wiring, not including major changes in distribution boards. The 1/4 lighting should be separated from the 3/4 of daylight-controlled lighting. A total cost of $1,800 (1,400 €) has been assumed to cover changes in zoning.

4.2.7.5 Payback Calculation

The calculated payback will occur in:

$1,800 / $417 / yr = 4.3 yrs

The total savings and investments for lighting ECMs in Building 4000 (LI #6 + LI#7) are:

Savings = 31.68MWh/yr + 5.21 MWh/yr = 36.89 MWh/yr

Savings = 36.89 MWh/yr x $80 / MWh = $2951/yr

Total Investment = $2,500 + 1,800 = $4,300

4.2.8 LI #8: Install Occupancy Sensors To Turn Off Unnecessary Lighting—Building 2371 Shipping and Receiving

4.2.8.1 Existing Conditions

The building is in operation 24 hrs a day. In the night shift there are usually three people, working at one end of the building. Lights are on all the time in this part and also in the separate storage room in the middle. The storage room has fluorescent lighting, the main part of the building having fixtures with mercury vapor or high pressure sodium lamps.

4.2.8.2 Solution

Install occupancy sensors in the storage room in the middle of the building. The occupancy time is only 2 to 3 hrs/day. Some security lighting should be on all the time.

4.2.8.3 Savings

Assuming that the lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day.

The lighting capacity to be controlled by the occupancy sensor is about 3.5 kW (including ballasts), assuming that out of the total amount of 28 luminaires four luminaires with 2x58W remain on all the time. Savings are calculated as:

Savings = 7 hrs/day x 240 days/yr x 3.5 kW x 1MW/1000kW = 5.88 MWh

Savings = 5.88 MWh x $80 / MWh = $470 / yr (362 €/yr)

4.2.8.4 Investment

A rough cost estimate is $250 for the sensor and some wiring. Here a total cost of $500 (385 €) has been assumed to cover changes in wiring to separate the security lights from the occupancy controlled luminaires.

$500 / $470 / yr = 1.1 yrs

4.2.9 LI #9: Install Occupancy Sensors To Turn Off Unnecessary Lighting—Building 2370 Security warehouse

4.2.9.1 Existing Conditions

The high security section (West end) of building is in operation about 10 hrs a day, but the lighting is on 24 hrs/day for security reasons. The area is fenced inside the KAD area. The lighting consists of 42 lighting fixtures with 400W mercury vapor or 250W high pressure sodium lamps (about 50/50 percent).

4.2.9.2 Solution

Install movement detector sensors at the fence and at the door to switch on all lights in the warehouse in unoccupied hours. Some security lighting should be on all the time.

If there is a recording surveillance camera in the warehouse, the camera may be connected to a movement detector and record only when there is movement (and lights are on). New camera types do not need light to function and record.

4.2.9.3 Savings

Assuming that the lighting can be switched off from 1606 on weekdays and 24 hrs during weekends reduces the weekly lighting time by 118 hrs/week.

The lighting capacity to be controlled by the occupancy sensor is about 13.8 kW (including ballasts). Savings are calculated as:

Savings = 118 hrs/week x 52 weeks/yr x 13.8 kW x 1MW/1000kW = 84.7 MWh

Savings = 84.7 MWh x $80 / MWh = $6,774 / yr (5,211 €/yr)

4.2.9.4 Investment

A rough cost estimate is $250 for the sensor and some wiring. Here a total cost of $2,500 (1,900 €) has been assumed to cover five IR-sensors, wiring and some security lighting.

4.2.9.5 Payback Calculation

The calculated payback will occur in:

$2,500 / $6,774 / yr = 0.4 yrs

4.2.10 LI #10: Install Occupancy Sensors To Turn off Unnecessary Lighting—Building 2225 Paint Booth

4.2.10.1 Existing Conditions

There is a paint booth in KAD Building 2225 that has a high lighting level. The lights are on even if there is nobody working in the paint booth. The typical lighting capacity per booth is 2.5 kW.

4.2.10.2 Solution

Install occupancy sensors in the paint booths to switch off most lights when there is no activity. Two-thirds of the lights could be switched off during the drying process when there is nobody in the booth. One third should remain on during working hours for safety reasons.

4.2.10.3 Savings

Assuming that two-thirds of the lighting can be switched off 70 percent of the time, the full lights on lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting capacity to be controlled by the occupancy sensor is 1.8 to 3.6 kW. Here it is assumed that the lighting capacity is 2.5 kW/booth. Savings are calculated as:

Savings per booth = 7 hrs/day x 240 days/yr x 2.5 kW x 1MW/1000kW x $80 / MWh = $336 / yr (258 €/yr)

4.2.10.4 Investment

A rough cost estimate is $250 for the sensor and some wiring. Here a total cost of $400 (300 €) has been used to cover the three paint booths.

4.2.10.5 Payback Calculation

The calculated payback will occur in:

$400 / $336 / yr = 1.2 yrs

4.2.11 LI #11: Install Occupancy Sensors To Turn Off Unnecessary Lighting—Building 4000 Paint Booths

4.2.11.1 Existing Conditions

There are two paint booths in Pirmasens Building 4000 that have a high lighting level. The lights are on even if there is nobody working in the paint booth. The typical lighting capacity per booth is 2.8 kW to 5.5 kW.

4.2.11.2 Solution

Install occupancy sensors in the paint booths to switch off most lights when there is no activity. Two-thirds of the lights could be switched off during the drying process when there is nobody in the booth. One third should remain on during working hours for safety reasons.

4.2.11.3 Savings

Assuming that two-thirds of the lighting can be switched off 70 percent of the time, the full lights on lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting capacity to be controlled by the occupancy sensor is in the different booths 1.8 to 3.6 kW. Here it is assumed that the lighting capacity is 2.5 kW/booth. Savings are calculated as:

Savings per booth = 7 hrs/day x 240 days/yr x 5 kW x 1MW/1000kW x $80 / MWh = $672 / yr (517 €/yr)

4.2.11.4 Investment

A rough cost estimate is $250 for the sensor and some wiring. Here a total cost of $800 (600 €) has been used to cover the two paint booths.

4.2.11.5 Payback Calculation

The calculated payback will occur in:

$800 / $672 / yr = 1.2 yrs

4.2.12 LI #12: Turn Off Halogen Lights When Stacker Is Not in Use—Building 2281 Stacker lights

4.2.12.1 Existing Conditions

In the middle and east end part of the building there is a stack lift for each aisle on both sides of the main aisle. Each stack lift has two halogen lights of about 150W. At the time of the visit three stack lifts had their halogen lights on although the stackers were not being used.

4.2.12.2 Solution

Repair the light controls on the stack lifts to avoid unnecessary lighting. The lights should be checked regularly to detect malfunctions.

4.2.12.3 Savings

Assuming that two stackers have the lights on all the time, the unnecessary lighting capacity is about 600W. The stack lift lights are on only when the lift is being used. The operation time per stacker is assumed to be about 10 minutes/day. Savings are calculated as:

Savings = 23.8 hrs/day x 365 days/yr x 600W x 1MWh/1,000,000W = 5.212 MWh/yr

Savings = 5.212 MWh/yr x $80 / MWh = $417/ yr (318 €/yr)

4.2.12.4 Investment

A rough cost estimate is $100 for the stack lift light contactor replacement per stacker. The cost should be included in the regular maintenance of the equipment. Here a total cost of $200 (150 €) has been assumed.

4.2.12.5 Payback Calculation

The calculated payback will occur in:

$200 / $414 / yr = 0.5 yrs

4.2.13 LI #13: Replace Lamp with More Efficient Type—Building 2371

4.2.13.1 Existing Conditions

In the warehouses, there are several different types of lighting fixtures with 400W mercury vapor lamps and 250W high pressure sodium lamps. Building 2371 has 200 lighting fixtures with about 40 percent mercury vapor lamps and 60 percent high pressure sodium lamps. Mercury vapor lamps have a lighting capacity of 35.2 kW (including ballasts).

4.2.13.2 Solution

Change mercury vapor lamps into high pressure sodium lamps.

Generally it is possible to replace 400W mercury vapor lamps by 250W high pressure sodium lamps without changes in the fixture, but if the fixture is old, the ballast may not be suitable for lamp type change. The high pressure sodium lamp produces more light with less power input—however, the color of the light from hp sodium lamps is different.

When the lamps are changed, the luminaires should be cleaned to improve reflecting capacity.

4.2.13.3 Savings

The lighting is usually on about 10 hrs on workdays. The savings have been calculated using 10 hrs/day. The lighting capacity will be reduced from 32 kW to 20 kW. Savings are calculated as:

Savings = 10 hrs/day x 240 days/yr x 13.6 kW = 32,640 KWh

Savings = 32,640 kWh x 1MW/1000kW x $80 / MWh = $2,611 / yr (2,008 €/yr)

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.2.13.4 Investment

Good quality high pressure sodium lamps are slightly more expensive than mercury vapor lamps, but the difference is very small (about $5 to $10/lamp). The number of lamps to be changed is about 80. This leads to a difference of $800 (615 €) in lamp change costs. The estimated lamp life-time is 10,000 – 15,000 hrs, so the lamps are changed every 4 to 5 yrs.

4.2.13.5 Payback Calculation

The calculated payback will occur in:

$800 / $2,611 / yr = 0.3 yrs

4.2.14 LI #14: Replace Lamp with More Efficient Type—Building 2370

4.2.14.1 Existing Conditions

In the warehouses there are several different types of lighting fixtures with 400W mercury vapor lamps and 250W high pressure sodium lamps. Building 2370 high security section has 42 lighting fixtures with about 50 percent mercury vapor lamps and 50 percent high pressure sodium lamps. Mercury vapor lamps have a lighting capacity of 9.2 kW (including ballasts).

4.2.14.2 Solution

Change mercury vapor lamps into high pressure sodium lamps.

Generally it is possible to replace 400W mercury vapor lamps by 250W high pressure sodium lamps without changes in the fixture, but if the fixture is old, the ballast may not be suitable for lamp type change. The high pressure sodium lamp produces more light with less power input, however the color of the light from hp sodium lamps is different.

When the lamps are changed, the luminaires should be cleaned to improve reflecting capacity.

4.2.14.3 Savings

The lighting is usually on about 10 hrs on workdays. In the 2370 security warehouse the lights are on all the time. The savings have been calculated using 10 hrs/day. The lighting capacity in this building will be reduced from 8.4 kW to 5.3 kW. Savings are calculated as:

Savings = 10 hrs/day x 240 days/yr x 3.57 kW = 8,658 KWh

Savings = 8,658 KWh x 1MWh/1000kWh x $80 / MWh = $685 / yr (527 €/yr)

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.2.14.4 Investment

Good quality high pressure sodium lamps are slightly more expensive than mercury vapor lamps, but the difference is very small (about $5 to $10/lamp). The number of lamps to be changed is about 21. This leads to a difference of $210 (160 €) in lamp change costs. The estimated lamp lifetime is 10,000 – 15,000 hrs, so the lamps are changed every 4 to 5 yrs.

4.2.14.5 Payback Calculation

The calculated payback will occur in:

$210 / $685 / yr = 0.3 yrs

4.2.15 LI #15: Replace Lamp with More Efficient Type—Building 2213

4.2.15.1 Existing Conditions

In the warehouses there are several different types of lighting fixtures with 400W mercury vapor lamps and 250W high pressure sodium lamps. Building 2213 has 20 lighting fixtures with mercury vapor lamps having a lighting capacity of 8.8 kW (including ballasts).

4.2.15.2 Solution

Change mercury vapor lamps into high pressure sodium lamps.

Generally it is possible to replace 400W mercury vapor lamps by 250W high pressure sodium lamps without changes in the fixture, but if the fixture is old, the ballast may not be suitable for lamp type change. The high pressure sodium lamp produces more light with less power input—however, the color of the light from hp sodium lamps is different.

When the lamps are changed, the luminaires should be cleaned to improve reflecting capacity.

4.2.15.3 Savings

The lighting is usually on about 10 hrs on workdays. The lighting capacity in this building will be reduced from 8 kW to 5 kW. Savings are calculated as:

Savings = 10 hrs/day x 240 days/yr x 3.4 kW = 8,160kWh

Savings = 8,160kWh x 1MW/1000kW x $80 / MWh = $653/ yr (502 €/yr)

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.2.15.4 Investment

Good quality high pressure sodium lamps are slightly more expensive than mercury vapor lamps, but the difference is very small (about $5 to $10/lamp). The number of lamps to be changed is about 20. This leads to a difference of $200 (150 €) in lamp change costs. The estimated lamp life-time is 10,000 to 15,000 hrs, so the lamps are changed every 4 to 5 yrs.

4.2.15.5 Payback Calculation

The calculated payback will occur in:

$200 / $653 / yr = 0.3 yrs

4.2.16 LI #16: Replace Lamp With More Efficient Type—Building 4171

4.2.16.1 Existing Conditions

In the warehouses there are several different types of lighting fixtures with 400W mercury vapor lamps and 250W high pressure sodium lamps. Building **4171** building part C has 42 mercury vapor lamps with a total lighting capacity of 18.4 kW (including ballasts).

4.2.16.2 Solution

Change mercury vapor lamps into high pressure sodium lamps.

Generally it is possible to replace 400W mercury vapor lamps by 250W high pressure sodium lamps without changes in the fixture, but if the fixture is old, the ballast may not be suitable for lamp type change. The high pressure sodium lamp produces more light with less power input—however, the color of the light from hp sodium lamps is different.

When the lamps are changed, the luminaires should be cleaned to improve reflecting capacity.

4.2.16.3 Savings

The lighting is usually on about 10 hrs on workdays. The lighting capacity in this building will be reduced from 16.8 kW to 10.5 kW. Savings are calculated as:

Savings = 10 hrs/day x 240 days/yr x 7.14 kW = 17,136kWh/yr
Savings = 17,136kWh/yr x 1MW/1000kW x $80 / MWh = $1,371/ yr (1,055 €/yr)

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.2.16.4 Investment

Good quality high pressure sodium lamps are slightly more expensive than mercury vapor lamps, but the difference is very small (about $5 to $10/lamp). The number of lamps to be changed is about 42. This leads to a difference of $420 (320 €) in lamp change costs. The estimated lamp lifetime is 10,000 – 15,000 hrs, so the lamps are changed every 4 to 5 yrs.

Payback: $420/$653/yr = 0.3 yrs

4.2.17 LI #17: Replace Lamp With More Efficient Type—Building 4171 Warehouse: Fluorescent Lights

4.2.17.1 Existing Conditions

In 4171 the warehouse sections A and B have fluorescent lighting. The lighting fixtures are possibly from the 1970s or 1980s and have a white reflectors and 65W fluorescent tubes. Total number of fixtures (and tubes) is about 580.

4.2.17.2 Solution

Change old thicker fluorescent tube (65W) into more energy efficient tube type (58W).

Usually it is possible to replace the tube type without changes in the luminaire, but if the fixture is old, the ballast may not be suitable for lamp type change. This should be checked before changing the tube type.

When the fluorescent tubes are changed, the luminaires should be cleaned to improve their reflecting capacity. Changing white reflectors to brighter ones is not recommended, the expected remaining life-time of the existing luminaires is 10 to 15 yrs.

4.2.17.3 Savings

The lighting capacity per tube is reduced by 7W and in all fixtures 4.1 kW. The lighting is usually on about 10 hrs on workdays. Savings are calculated as:

Savings = 10 hrs/day x 240 days/yr x 4.1 kW = 9,840 kWh/yr

Savings = 10 hrs/day x 240 days/yr x 4.1 kW x 1MW/1000kW x $80 / MWh = $787 / yr (600 €/yr)

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.2.17.4 Investment

There is no difference in tube price for the 65W and 58W tubes. All tubes should be replaced at the same time to minimize change work costs.

4.2.17.5 Payback Calculation

There will be zero payback time; tubes need to be changed anyway after about 10,000 hrs of use (approximately every 4 yrs).

4.2.18 LI #18: Install Energy Efficient Lighting in Renovations—Building 4155 (Under Renovation) and Other Buildings

4.2.18.1 Existing Conditions

In 4155 new lighting fixtures with ordinary 36W fluorescent tubes were being installed in the rooms under renovation. It is estimated that there will be 200 fixtures.

4.2.18.2 Solution

To improve energy efficiency of old fluorescent lighting fixtures, it is not possible to change into the new more efficient and low power input tube type to T5, but new fixtures are needed. By renovating the fixtures less fixtures are needed for the same amount of light. The power input of a single tube 58W fixture will go from 73W (including ballast) down to about 55W if a T5 fixture is installed.

4.2.18.3 Savings

Savings are calculated as:

Savings = 200 fixtures x 10 hrs/day x 240 days/yr x 18W = 8,640 KWh/yr
Savings = 8,640 kWh/yr x 1MW/1,000,000W x $80 / MWh = $691 / yr (532 €/yr)

4.2.18.4 Investment

The new T5 fixture costs about $180 and an ordinary single-tube 58W fixture costs (depending on manufacturer and luminaire type) $130 to $180. The price difference is assumed to be $5 (3.84 €) or $1000 (769 €) for 200 fixtures.

4.2.18.5 Payback Calculation

The calculated payback will occur in:

Per fixture $1,000 / $691 / yr = 1.4 yrs

The conclusion is that when the electrical system or lighting installation in a building is renovated for technical reasons and new fixtures are installed, more energy efficient T5 fixtures should be installed instead of the ordinary type.

According to a fluorescent tube manufacturer's tests the expected life-time of T5 lamps is about 20,000 hrs whereas for an ordinary 36W or 58W tube the efficient life-time is only 4,000 hrs, after this the amount of light from the tube will begin to decrease.

4.2.19 LI #19: Paint Ceiling White To Improve Lighting Level—Building 4171 Outbound Storage

4.2.19.1 Existing Conditions

In 4171 the building section C has a dark interior ceiling covered with mineral wool insulation elements. This leads in decreased lighting level.

4.2.19.2 Solution

Paint the ceiling white with paint suitable for mineral wool surfaces. Also a white surface material is possible—this would keep fibers from the mineral wool from being carried into the indoor air by air movement.

4.2.19.3 Savings

No saving can be indicated; the lights in the warehouse are on all day. The lighting level would be improved. This has an effect on worker safety and indoor environment. The following sections include calculated savings.

4.2.19.4 Investment

In the Fort Stewart, GA energy audit report* the cost of painting was estimated as $2.40/sq ft. The area of Section C is roughly 40,000 sq ft. The cost of painting the ceiling is about $96,000 (73,800 €).

4.2.19.5 Payback Calculation

The calculated payback is unknown.

4.2.20 ECM Summary

Table 5 lists the ECM summary for Kaiserslautern and Pirmasens lighting (LI).

* Vavrin, John L., Alexander M. Zhivov, William T. Brown, David M. Underwood, Al Woody, Hashem Akbari, Marvin Keefover, Stephen Richter, James Newman, Robert Miller, Arturo Hernandez, David Kulikowski, Aaron Hart, and Fred Louis. April 2006. *Energy and Process Optimization Assessment: Fort Stewart, GA*, ERDC-CERL TR-06-08/ADA449505, Champaign, IL.

Table 5. Kaiserslautern and Pirmasens lighting (LI) ECM summary.

ECM	ECM Description	Electrical Savings MWh/yr	$K/yr	Thermal Savings MWh/yr	$K/yr	Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
LI1	Install Energy Efficient LED Exit Lights - Kaiserslautern and Pirmasens	16	1.3				1.3	10.8	8.2
LI2	Install Occupancy Sensors to Turn off Unnecessary Lighting, All buildings: Restrooms, lunchrooms, etc – Kaiserslautern and Pirmasens	10	0.8				0.8	5.0	6.2
LI3	Use Daylight Sensors to Turn off Unnecessary Lighting Building 2233 Maintenance Area	37	3.0				3.0	2.5	0.8
LI4	Use Daylight Sensors to Turn off Unnecessary Lighting, Building 2233 - Engine repair and other areas on the North side	40	3.0				3.0	2.5	0.98
LI5	Install daylight sensors to switch off unnecessary lighting during daylight hours, Building 2281 Warehouse SAK	30	2.4				2.4	2.5	1.0
LI6	Install daylight sensors to switch off unnecessary lighting during daylight hours, Building 4000 Maintenance Area and Bodyshop	37	3.0				2.95	4.3	1.5
LI7	Install daylight sensors to switch off unnecessary lighting during daylight hours, Building 4000 Maintenance-Apprentice Workshop	5.21	0.42				0.42	1.8	4.3
LI8	Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2371 Shipping and receiving	6	0.5				0.5	0.5	1.1
LI9	Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2370 Security warehouse	85	6.8				6.8	2.5	0.4
LI10	Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2225 Paint booth	4.2	0.3				0.3	0.4	1.2
LI11	Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 4000 Paint booths	8.4	0.7				0.7	0.8	1.2
LI12	Turn off Halogen Lights When Stacker is not in Use, Building 2281 Stacker lights	5.2	0.4				0.4	0.2	0.5
LI13	Replace Mercury Vapor Lamp with More Efficient Type, Building 2371	33	2.6				2.6	0.8	0.3
LI14	Replace Mercury Vapor Lamp with More Efficient Type, Building 2370	9	0.7				0.7	0.2	0.3
LI15	Replace Mercury Vapor Lamp with More Efficient Type, Building 2213	8	0.7				0.7	0.2	0.3
LI16	Replace Mercury Vapor Lamp with More Efficient Type, Building 4171	17	1.4				1.4	0.4	0.3
LI17	Replace Fluorescent Lamp with More Efficient Type, Building 4171 Warehouse: fluorescent lights	10	0.8				0.8	0.4	0.5
LI18	Install Energy Efficient Lighting in Renovations, Building 4155 (under renovation) and other buildings	8.6	0.72.5				0.72.5	1.02.5	1.40
LI20	Improve Lighting Efficiency In Hangers (No Economic Analysis)								
Total	Kaiserslautern and Pirmasens Lighting ECMs	367	29.52	0	0	0	29.5	36.8	1.2

4.3 Kaiserslautern Building Envelope (BE)

4.3.1 BE #1: Use Transparent Plastic Panels Behind Glass Sash—Building 2233

4.3.1.1 Existing Conditions

Building 2233 is a large tall building used to repair all sizes of Army vehicles (Figure 3). The building is over 50 yrs old, but in good condition. The building has a very high percentage of single pane glass in the outer walls and roof. Above a height of approximately 4m the walls are mostly glass. There are also large skylights in the roof area allowing sunlight to enter the building. This provides a lot of natural light for the building occupants and general building lighting is not needed on bright days. The glass area in the roof is approximately 44,000 sq ft in area and the window area in the walls is estimated to be 26,000 sq ft.

Figure 3. Kaiserslautern Building 2233.

The single pane glass creates thermal problems inside the building. First it has a poor insulating value and much building heat is loss to the outside in the winter. Second, the operable sections of the glass areas are hard to close. These openings are needed in the summer to help vent off the warm air that collects in the upper region of the building. If the windows do not close well, the resulting openings increase the amount of infiltration that enters the building in the winter making it more difficult to heat the building. Third the sunshine can enter the building causing an increased cooling load in the summer. Since there is no way to lower the summertime building temperature other than opening doors to allowing outside air to flow through the building the space temperatures become so warm that an additional 15-minute break is provided to the workers in the morning and afternoon on hot days.

4.3.1.2 Solution

Install transparent plastic panels behind the existing glass windows. Place the new panels as close to the glass windows as possible to provide a dead air space. The windows need to be inspected before the plastic panels are installed. Replace all broken windows and seal all openings and cracks between the windows, frames, and building structure. Remove operable hardware that allows the windows to open so that it will not interfere with the panel installation. Frame around locations where stacks penetrate the window area and where exhaust fans are planned to be placed.

The new plastic panels will allow most of the natural light to enter the building. The panels will provide a resistance to heat transfer due to layers of isolated air spaces in the panels. The proposed panel has three such layers providing an insulation value of approximately 0.5 Btu/sq ft/°F. It is planned to place these panels immediately under the existing windows leaving an air space as narrow as possible for an insulation value of approximately 0.35 Btu/sq ft/°F for the panel/window combination.

4.3.1.3 Savings

The placement of the transparent panels behind the existing windows will reduce the heat loss through the windows by 70 percent. Savings are calculated as:

$$Q = (1.17 - 0.35) \text{ Btu/sq ft/ °F X } 70{,}154 \text{ sq ft X } (64.4 - 39) \text{ °F X } 6000 \text{ hrs/yr / } 3413000 \text{ Btu/MWH} = 2569 \text{ MWH/yr}$$

The total energy cost savings is therefore $167,000 or 128,000 €/yr:

Cost Savings = (2,569) MWHth X $65/MWh = $167,000/yr

4.3.1.4 Investment

The estimated cost to prepare the underside of the windows and install the new transparent panels is $15/sq ft or $1,052,000 (809,000 €).

4.3.1.5 Payback Calculation

The resulting payback period for the window enhancement is 6.3 yrs.

4.3.2 BE #2: Reduce Solar Heat Load by Use of Conventional or Spectrally Selective Solar Film, Building 2233

4.3.2.1 Existing Conditions

For existing conditions in Building 2233, see BE #1.

4.3.2.2 Solution

Install solar film on the inside of the existing glass windows. The windows need to be inspected before the solar film is installed to ensure there are no cracked panes, loose glazing, spaces between the frames and the building, operable windows that do not close, etc. All openings between the window frames and building structure must be properly sealed and other repairs must be made as required. Openings where stacks penetrate the windows for exhaust fans must be properly framed to eliminate infiltration of outside air, and contribute to the "stack effect" of exfiltration in the winter.

There are two different types of window film, conventional and "spectrally-selective." Conventional dark and reflective applied window films successfully block a significant amount of solar heat, thereby reducing the cooling problem in the interior space. However, these same films reduce a significant amount of visible light through the glass. The result, on many days of reduced sunlight, is that increased illumination is required, thus increasing both the heat in the space and the energy required to maintain the proper light levels.

The term "spectrally selective" refers to the ability of the film to select or "let in" desirable daylight, while blocking out undesirable heat. Most dark and reflective films transmit less than 35 percent of visible light and correspondingly appear unclear. True spectrally selective film blocks minimally less heat than the darkest conventional films (2 to 10 percent depending on the manufacturer), while typically transmitting 70 percent of the visible light. By transmitting more of the visible light, it also allows the use of less lighting energy. However, to accomplish this lower energy usage, either photosensors at the working level or manual shutoff of lights must be used. See LI #1 (p 15).

Since the windows are high above the floor, the lower heat blockage is not a severe problem like it would be in an office building, as the higher heat gain would remain in the upper parts of the building in the monitor areas, well above the working level, where it could be removed by properly sized exhaust fans. The key to success here is to minimize the solar load at the working level to minimize the effect of heat on the workers in the summertime, while still providing enough natural light so that less electric energy can be used for the lighting.

4.3.2.3 Savings

<u>Conventional Window Film:</u>

Using reflective film, the percentage of solar energy typically transmitted through the glass is 44 percent. The percentage of daylight transmitted is 37 percent. Savings are calculated as:

> The heat gain in the summertime will be reduced by [1.17 x (1.00 – 0.44)] Btu/sq ft/°F x 70,000 sq ft x (91 – 80)°F x 5 months/yr x 23 days/month x 8 hrs/day / 3413000 Btu/MWh = 136 MWh / yr.

There is no cost savings associated with the decrease of the heat gain, since the plant is not air-conditioned. However, the difference in temperature at the floor level due to the decrease in the heat gain from the sun should minimize or eliminate the need for additional 15 minute breaks, increasing employee productivity. Assuming that the additional morning break could be eliminated, and the afternoon break shortened, the savings would be:

> 180 men x 0.33 hr/day x 20 days/yr x $60/hr = $70,000.

<u>Spectrally Selective Window Film:</u>

With this type of film, the percentage of solar energy transmitted is 45 to 50 percent, while the daylight transmitted can be as high as 70 percent.

Using the above calculations for conventional window film, the savings from the reduced break time would be the same $70,000.

In addition, because of the better light transmittance, the electric lighting could be reduced with a concurrent saving of approximately $2300/yr.

Further, the spectrally selective glass would allow the workers to see outside as though there were no barrier, contributing to a sustained sense of health and productivity.

Total savings are $72,300/yr.

4.3.2.4 Investment

Conventional Window Film:

The installed cost for a project of this size would be approximately $4.00/sq ft.

With approximately 70,000 sq ft of window area, the total investment would be $280,000.

Spectrally Selective Window Film:

The installed cost would be approximately $9.00/sq ft = $630,000.

4.3.2.5 Payback Calculation

The calculated payback (obviously not a cost-effective solution) is:

Conventional Window Film:

$280,000 / $70,000 = 4.0 yrs

Spectrally Selective Film:

$630,000 / $72,300 = 8.7 yrs.

Spectrally selective film is more suited for office buildings, schools, store windows, etc., but it was analyzed to show the difference, as spectrally selective film is becoming more of a factor in the marketplace. Further, you may want to analyze this type of window film in the future for other types of buildings, such as barracks, offices, etc.

NOTE: The “Savings” shown above are also included in HV #4 and HV #5. Because the investment in those ECOs is considerably less, and similar results would be achieved, those would be better solutions than window film. Further, installing the proper type and size of air circulating fans, would contribute to comfort of the workers thereby increasing their productivity even on days where they did not have to take extra breaks.

4.3.3 BE #3: Add Vestibule on West Side Door—Building 2233

4.3.3.1 Existing Conditions

In Building 2233 doors are opened throughout the day to allow for trucks needing maintenance to enter and exit and to allow travel of fork trucks that carry materials and parts between buildings. Mostly the doors at the ends of the building are used. Recently rapid roll-up doors have been installed on these two doors to reduce the time they are open (Figure 4). The door on the west end of the building gets the most use.

Figure 4. Rapid roll-up doors in west side of Building 2233.

When these doors are open in the winter large amounts of cold air enters the building. This causes cold areas in the building where it is hard to work and makes heating the building difficult.

It was also noted that there was an opening about one foot high above the door that ran the width of the door. This opening is also allowing cold air to enter the building in the winter.

4.3.3.2 Solution

A vestibule that is approximately 60 ft long by 25 ft wide could be added to the door opening on the west side. If room permits the vestibule would be outside the building. The existing door would be one end of the vestibule with a new door installed at the other end. Small vehicles and fork trucks would enter one end of the vestibule. The outside door would be shut after they had passed through and the inside door would open to allow entry into the building. This way there would be an air lock between the inside and outside of the building minimizing the amount of cold air that enters.

4.3.3.3 Savings

Adding this vestibule will reduce the amount of outside air infiltrating the building by 24,000 CFM when the door is open. Assuming the door is open 10 minutes/hour of operation, the annual energy savings is:

Q = 1.08 X 24,000 CFM (64.4 – 39) °F X 10 min/ hr X 9 hr/day X 140 days/yr/ 3413000 Btu/MWH = 40.5 MWHth/yr

There is also an opening above the door that the vestibule would close thereby eliminating the infiltration of 2000 CFM:

Q = 1.08 X 2,000 CFM (64.4 – 39) °F X 6000 hrs/yr/ 3413000 Btu/MWH = 96.5 MWHth/yr

The total energy cost savings is therefore $8,900 (6,800 €)/yr:

Cost Savings = (40.5 +96.5) MWHth X $65/MWH = $8,905/yr

4.3.3.4 Investment

The proposed vestibule would be 60 ft long by 25 ft wide, having an area of 1,500 sq ft. The estimated cost for such a vestibule is $70/sq ft, or $105,000 (81,000 €). The vestibule would be constructed of metal frame walls. Another rapid roll-up door would be required as would lighting in the new area.

4.3.3.5 Payback Calculation

The resulting payback of this project is 11.8 yrs.

4.3.4 BE #4: Use Light Shelves for Additional Natural Lighting—Building 2233

4.3.4.1 Existing Conditions

Figure 5 shows how the glass in the roof and windows along the sides of Building 2233 bring enough light into the building on a bright, sunny day during all seasons of the year so work can be performed without the use electric lighting in the main area of the building. See ECM L1 #1 (p 15).

Figure 5. Light shelves in Building 2233.

The areas in the north side of the building do not have the availability of as much natural light as in the main part.

4.3.4.2 Solution

Install "light shelves" to bring the daylight further into the building on the north side. Light shelves are surfaces with reflective upper sides, located near the top of windows. They allow light to penetrate further into the building by reflecting some of the light off the ceiling, which allows the light to penetrate further into the building. This would allow the general space lighting to be put on photo sensors so they could be switched off when there is enough light provided by daylight. The “task” lighting could still be on separate circuits and only shut off when not needed.

4.3.4.3 Comments

Light shelves are considerably more effective on the south and west sides of a building than the north side. After analysis, it was decided that this concept was not a cost-effective or even a viable solution for Building 2233, as it was not necessary for the main areas on the south and center of the building, and would not be an effective solution for the engine repair and other areas on the north side.

4.3.5 BE #5: Provide Insulated Panels for Door Openings—Building 2222

4.3.5.1 Existing Conditions

In Building 2222 there are eight bifold doors along the north side of the building. These doors are seldom used and have equipment and parts placed in front of them. These doors are approximately 17.5 ft wide by 12 ft high and appear to have approximately 1 in. of insulation providing a total insulating value of 0.21 Btu/sq ft/°F.

4.3.5.2 Solution

These door openings can be filled with an insulated removable panel to provide a greater resistance to heat loss. The proposed door panels would be fiber glass or metal covered foam sections the height of the door that are placed behind the existing doors. These door panels would be screwed together providing a smooth surface. Provisions will be made to allow easy disassembly if a door needs to be opened. The estimated new insulating value of the door with a panel is 0.09 Btu/sq ft/°F.

The door area should be inspected before these panels are installed and all cracks should be sealed or gasketed to provide a weather tight barrier. This will reduce the amount of cold air that infiltrates the building during the winter.

4.3.5.3 Savings

The estimated energy savings of these door panels is 9 MWHth/yr providing an annual cost savings of $585. The installation of the door panels will also reduce the amount of outside air that enters to building providing an additional savings of 19 MWHth for a cost savings of $1,254/yr. Savings are calculated as:

$Q_{Conduction}$ = (0.21 – 0.09) Btu/sq ft/ °F X 1,680 sq ft X (64.4 – 39) °F X 6000 hrs/yr / 3413000 Btu/MWH = 9.0 MWHth/yr

$Q_{Infiltration}$ = 1.08 X 400 CFM (64.4 – 39) °F X 6000 hrs/yr/ 3413000 Btu/MWH = 19.3 MWHth/yr

Qtotal = 28.3 MWHth/yr

Cost Savings = (9.0 +19.3) MWHth X $65/MWH = $1,840/yr (1,420 €)

4.3.5.4 Investment

The total door area to be filled is 1,680 sq ft. Using a cost of $10/sq ft the total estimated installed cost is $16,800 (12,900 €).

4.3.5.5 Payback Calculation

The total energy savings is $1,840/yr resulting in a payback of the installation of these door panels of 9.1 yrs.

4.3.6 BE #6: Repair Door Seals—Building 2226

4.3.6.1 Existing Conditions

In Building 2226, there are several doors that need repair so that they seal the door opening when they are closed. The openings caused by the damaged door frames allow cold air to infiltrate into the building in the winter. This causes cold drafts and increases the heating demand.

4.3.6.2 Solution

Repair the door frames so that the door openings are properly sealed. Add seals and replace door panels where necessary.

4.3.6.3 Savings

Approximately 200 CFM of outside air is estimated to enter the building due to these door leaks causing an energy use of almost 10 MWHth/yr. The annual energy cost of this additional heat is $630 (480 €). Savings are calculated as:

Q = 1.08 X 200 CFM (64.4 – 39) °F X 6000 hrs/yr/ 3413000 Btu/MWH

= 9.7 MWHth/yr

The total energy cost savings is therefore $630 (480 €)/yr:

Cost Savings = (9.7) MWHth X $65/MWH = $630/yr

4.3.6.4 Investment

The estimated cost to repair each door is $1,000 for a total repair cost of $2,000 (1,540 €).

4.3.6.5 Payback Calculation

The resulting payback of repairing the doors is 3.2 yrs.

4.3.7 BE #7: Add Vestibule on West Side of Building Going-Up Ramp—Building 2371

4.3.7.1 Existing Conditions

Building 2371 is the major shipping facility at the depot. Here parts for a shipment are assembled from various warehouses onto pallets and placed in trailers for transport. On the west side of the building, one door is used in the route to the adjacent warehouses. As the result, this door is open a good percentage of the time and cold drafts are common in the adjacent area (Figure 6). This makes this space very uncomfortable in the winter and additional heat is used.

Figure 6. Door seals on Building 2226.

4.3.7.2 Solution

As you exit this door you proceed down a covered ramp to street level for traveling to nearby warehouses. This vestibule can be easily enclosed by adding walls and a door at the end. Then there will be doors at each end, which will be controlled such that one door will open to allow the fork truck to enter. Once the fork truck is inside the first door a will close and the second one will open. This air lock will minimize the cold air that enters the building.

4.3.7.3 Savings

It is estimated the vestibule will eliminate the infiltration by 12000 CFM (100FPM), which occurs an estimated 25 percent of the time. Savings are calculated as:

Q= 1.08 X 12,000 CFM X 0.25 X (64.4 – 39) °F X 6000 hrs/yr/ 3413 MWH/Btuh
= 145 MWHth

Energy cost savings = 145 MWHth X \$65/MWHth = \$9,404/yr (7,230 €)

4.3.7.4 Investment

The distance down the ramp is 84 ft. The width is 15 ft for an area of 1260 sq ft. Using a cost of $40/sq ft, the vestibule cost would be $50,400 (41,500 €).

4.3.7.5 Payback Calculation

The resulting simple payback of the vestibule is 5.4 yrs.

4.3.8 BE #8: Place Insulated Panel in Unused Door Areas—Building 2371

4.3.8.1 Existing Conditions

In Building 2371, there are six truck doors along the west side of the building are seldom used and have equipment and parts placed in front of them (Figure 7). These metal roll-up doors are approximately 12 ft wide by 10 ft high with no insulation. The estimated insulating value of a door is 1.11 Btu/sq ft/°F.

Figure 7. Uninsulated, unused doors in Building 2371.

4.3.8.2 Solution

These door openings can be filled with an insulated removable panel to provide a greater resistance to heat loss. The proposed door panels would be fiber glass or metal covered foam sections the height of the door that are placed behind the existing doors. These door panels would be screwed together providing a smooth surface. Provisions will be made to allow easy disassembly if a door needs to be opened. The estimated new insulating value of the door with a panel is 0.09 Btu/sq ft/°F.

The door area should be inspected before these panels are installed and all cracks should be sealed or gasketed to provide a weather tight barrier. This will reduce the amount of cold air that infiltrates the building during the winter.

4.3.8.3 Savings

The estimated energy savings of these door panels is 32 MWHth/yr providing an annual cost savings of $2,112. The installation of the door panels will also reduce the amount of outside air that enters to building providing an additional savings of 19 MWHth for a cost savings of $1,254/yr. Savings are calculated as:

$$Q_{conduction} = (1.1 - 0.09)\ \text{Btu/sq ft/ °F X 720 sq ft X } (64.4 - 39)\ \text{°F X 6000 hrs/yr / 3413000 Btu/MWH} = 32.5\ \text{MWHth/yr}$$

$$Q_{infiltration} = 1.08\ \text{X 400 CFM } (64.4 - 39)\ \text{°F X 6000 hrs/yr/ 3413000 Btu/MWH} = 19.3\ \text{MWHth/yr}$$

The total energy cost savings is therefore $3,367(2,590 €)/yr.

Cost Savings = (32.5 +19.3) MWHth X $65/MWH = $3,367/yr

4.3.8.4 Investment

The total door area to be filled is 720 sq ft. Using a cost of $10/sq ft, the total estimated installed cost is $7,200 (5,500 €).

4.3.8.5 Payback Calculation

The total energy savings is $3,367/yr resulting in a payback of the installation of these door panels of 2.1 yrs.

4.3.9 BE #9: Repair Damaged Doors—Building 2371

4.3.9.1 Existing Conditions

In Building 2371 there are several doors that are damaged, allowing outside air to enter the building.

This is more serious in the winter than in the summer, as the wind velocity is higher and the cold drafts increase worker discomfort and increase heating demand.

4.3.9.2 Solution

Repair doors, including frames and seals as necessary.

4.3.9.3 Savings

Based on the conservative assumption that approximately 200 cfm of outside air/door enters the building due to door leaks, the additional energy use amounts to close to 10 MWh/yr. Savings are calculated as:

1.09 x 200 cfm x (64.4 – 39) °F x 6000 hrs/yr / 3,413,000 Btu/MWh = 9.7MWhth/yr

The cost savings = 9.7 MWh/yr x $65/MWh = $630/yr/door

4.3.9.4 Investment

It is dependent on the damage to the door and the type and amount of repair required, but the estimated cost to repair most of the doors is approximately $1000.

4.3.9.5 Payback Calculation

The calculated payback will occur in:

The payback = $1000/$630 = 1.6 yrs.

4.3.10 BE #10: Insulate North Wall—Building 2371

4.3.10.1 Existing Conditions

The north wall of Building 2371 is an uninsulated block wall, 180 ft long and approximately 25 ft high.

The workers in the north end of the building commented that it is much colder there than in the other parts of the building, even though the HVAC system is newer there, and supposedly operating properly.

4.3.10.2 Solution

The HVAC system should be checked to make sure it is operating properly, both for the volume of air being distributed into the space and for the temperature rise through the coils.

The wall should be checked to ensure there are no leaks that allow excessive infiltration and repaired if necessary, especially where the wall meets the roof.

Insulating the wall with will considerably reduce the cold air from conduction and radiation in the wintertime.

The analysis is based on 3-in. thick pinned-in-place rigid board insulation, and no exterior covering, as there are no workers near that wall.

4.3.10.3 Savings

The energy savings of the insulated wall is 49.8 MWhth/yr, providing an annual cost savings of $3237. These calculations are conservative as they do not take into account the potential reduction in infiltration.

Q = (0.308 – 0.06) Btu/hr/sq ft/°F x 4500 sq ft x (64.4 – 39) °F x 6000 hrs/yr / 3413000Btu/MWh = 49.8 MWh/yr

Energy cost savings = 49.8 MWh x $65/MWh = $3237 / yr

4.3.10.4 Investment

The approximate total area of the wall is 4500 sq ft. The estimated cost to install the insulation is:

4500 sq ft x $5.00/sq ft = $22,500.

4.3.10.5 Payback Calculation

The calculated simple payback will occur in 7 yrs.

4.3.11 BE #11: Use Transparent Plastic Panels Behind Glass Windows—Building 2281

4.3.11.1 Existing Conditions

The windows are single pane about 12 ft above the floor and continuous along the north and south sides of the building. Single pane glass has a poor insulating value. This allows much heat to escape during the cold months and similarly allows a considerable solar load in the summer months leading to thermal problems within the building, i.e., too cold in the winter and too hot in the summer.

4.3.11.2 Solution

Inspect all windows to ensure there are no broken windows, loose glazing, space between the frames and the building, etc. Repair as required.

Install transparent plastic panels behind the existing glass windows, as close to the glass as possible so that a dead air space will be provided. These panels will allow almost as much light to enter the building as does the single pane glass, thus not increasing the usage of the electric lighting. By using a three-layer panel, as in BE #1, the resistance to heat loss and heat gain (heat gain not considered in the energy saving calculation since there is no mechanical air-conditioning) by 0.50 Btu/sq ft/°F. The combined insulating value of the glass plus the panel is 0.35 Btu/sq ft/°F.

4.3.11.3 Savings

Using this type of transparent panel behind the existing windows will reduce the heat loss through the windows by 70 percent, or 158 MWh/yr for an energy cost savings of $10,270/yr. Savings are calculated as:

Q = (1.17 – 0.35) Btu/hr/sq ft/°F x 4312 sq ft x (64.4 – 39) °F x 6000 hrs/yr / 3413000Btu/MWh = 158 MWhth/yr

Cost savings = 158 MWh/yr x $65 / MWh = $10,270/yr

4.3.11.4 Investment

The estimate cost to prepare the underside of the windows and to install the new panels is $15/sq ft or $64,680.

4.3.11.5 Payback Calculation

The resulting simple payback period is 64680 / 10270 = 6.3 yrs.

4.3.12 BE #12: Use Transparent Plastic Panels To Replace Roof Skylights—Building 2281

4.3.12.1 Existing Conditions

The roof is slightly pitched with two rows of single translucent panels (skylights) running the length of the building, with a total area of 3520 sq ft (Figure 8). These panels have no insulating value and are also very dirty, minimizing the amount of light allowed through.

Figure 8. Roof skylights in Building 2281.

4.3.12.2 Solution

Replace the existing panels with the same three-layer panels as in BE #1.

4.3.12.3 Savings

The heat loss will be reduced by 118 MWh/yr, leading to an energy savings of $7670/yr. Savings are calculated as:

Q = (1.10 – 0.35) Btu/hr/sq ft/°F x 3520 sq ft x (64.4 – 39)°F x 6000 hrs / 3413000Btu/MWh = 118 MWhth / yr

Energy cost savings = 118 x $65 = $7670.

4.3.12.4 Investment

Removing the existing single pane panels and replacing them with triple pane panels is estimated at $20/sq ft or $70,400.

4.3.12.5 Payback Calculation

The resulting simple payback is 9.2 yrs.

4.3.13 BE #13: Repair and Insulate Roof Building 2281

4.3.13.1 Existing Conditions

The existing 18,700 sq ft roof, which has only a moderate pitch, is a wooden structure with no insulation and with numerous leaks. For purposes of calculation, without having gone up on the roof, 5/8-in. plywood with asphalt roll roofing and asphalt shingles are assumed.

4.3.13.2 Solution

Remove existing roofing material and install new roof with 2-in. insulation board (R=10).

4.3.13.3 Savings

The heat loss will be reduced by 372 MWhth/yr, leading to an energy savings of $24,180/yr. Savings are calculated as:

Q = (0.40 – 0.08) Btu/hr/sq ft/°F x 18,700 sq ft x (64.4 – 29) °F x 6000 hrs/yr / 3413000 Btu/MWh = 372 Mwhth / yr

Energy cost savings = 372 x $65 = $24,180.

4.3.13.4 Investment

The cost to remove the existing roof and replace it is estimated to be $8.00/sq ft = $149,600.

4.3.13.5 Payback Calculation

The resulting simple payback is 6.2 yrs.

4.3.14 BE #14: Repair Door Seals—Building 2370

4.3.14.1 Existing Conditions

In Building 2370 there are several doors that need repair so that they seal the door opening when they are closed. The openings caused by the damaged door frames allow cold air to infiltrate into the building in the winter. This causes cold drafts and increases the heating demand.

4.3.14.2 Solution

Repair the door frames so that the door openings are properly sealed. Add seals and replace door panels where necessary.

4.3.14.3 Savings

Approximately 200 CFM of outside air is estimated to enter the building due to these door leaks causing an energy use of almost 10 MWHth/yr. The annual energy cost of this additional heat is $627 (482 €). Savings are calculated as:

Q = 1.08 X 200 CFM (64.4 – 39) °F X 6000 hrs/yr/ 3413000 Btu/MWH
= 9.6 MWHth/yr
Cost Savings = 9.6 MWHth X $65/MWH = $627/yr

4.3.14.4 Investment

The estimated cost to repair each door is $1,000 for a total repair cost of $2,000 (480 €).

4.3.14.5 Payback Calculation

The resulting payback of repairing the doors is 3.2 yrs.

4.3.15 BE #15: Insulate Roof in Maintenance Building #2226, Kaiserslautern

Heating system is connected to the district heating.

4.3.15.1 Problem

High heat losses due to the absence of roof insulation

4.3.15.2 Solution

Insulate the roof

4.3.15.3 Estimated Energy Saving and Costs

Existing insulation: u = 2 W/m^2K

New insulation: u = 0.5 W/m^2K

Area: 1,640 m^2

Mean outside temperature: 4 °C

Use: 8 h/d ; 5 d/w ; 200 d/yr (= 1,140 h/yr)

Energy costs: $65/MWh

Energy losses with existing insulation:

2 W/m^2K * 1,640 m^2 * (20-4) K * 1,140 h/yr = 59.8 MWh/yr

Energy losses with new insulation:

0.5 W/m^2K * 1,640 m^2 * (20-4) K * 1,140 h/yr = 15.0 MWh/yr

Saving: (59.8 – 15.0) MWh/yr * $65/MWh/yr= $2,912/yr

Cost of insulation: $20/$m^2$ * 1,640 m^2 = $32,800

Payback: $32,800/ $2,912/yr = 11.6 yrs

4.3.15.4 Problem

High heat losses due to the absence of roof insulation.

4.3.15.5 Solution

Insulate the roof.

4.3.15.6 Estimated Energy Saving and Costs

Existing insulation: u = 2 W/m^2K

New insulation: u = 0.5 W/m^2K

Area: 1,640 m^2

Mean outside temperature: 4 °C

Use: 8 h/d ; 5 d/w ; 200 d/yr (= 1,140 h/yr)

Energy costs: $65/MWh

Energy losses with existing insulation:

2 W/m^2K * 1,640 m^2 * (20-4) K * 1,140 h/yr = 59.8 MWh/yr

Energy losses with new insulation:

0.5 W/m^2K * 1,640 m^2 * (20-4) K * 1,140 h/yr = 15.0 MWh/yr

4.3.15.7 Savings

(59.8 – 15.0) MWh/yr * $65/MWh/yr= $2,912/yr

4.3.15.8 Cost of Insulation

$20/m² * 1,640 m² = $32,800

4.3.15.9 Payback

$32,800/ $2,912/yr = 11.6 yrs

Table 6 lists the ECM envelope (BE) summary for the Kaiserslautern buildings.

Table 6. Kaiserslautern building envelope (BE) ECM summary.

ECM	ECM Description	Electrical Savings MWh/yr	$k/yr	Thermal Savings MWh/yr	$k/yr	Additional Savings $K/yr	Total Savings $k/yr	Investment $k	Simple Payback yrs
BE1	Use transparent plastic panels behind glass sash, building 2233			2569	167.0		167	1052.0	6.3
BE2	a. Reduce solar heat load by use of conventional solar[1] film OR					70	70	280	4.0
	b. spectrically selective solar film	28.8	2.3			70	72.3	630	8.7
BE3	Add vestibule on west side door of building 2233			137	8.9		8.9	105.0	11.8
BE4	Use Light Shelves for Additional Natural Lighting[2] – Building 2233								
BE5	Provide insulated panels for door openings in building 2222			28.3	1.84		1.84	16.8	9.12
BE6	Repair door seals, building 2226			9.7	0.63		0.63	2.0	3.2
BE7	Add vestibule on west side of building going-up ramp in building 2371			145	9.4		9.4	50.4	5.3
BE8	Place insulated panel in unused door areas in building 2371			51.8	3.4		3.4	7.2	2.1
BE9	Repair Fix damaged doors in building 2371			9.7	0.6		0.6	1.0	1.6
BE10	Insulate north wall bldg 2371			49.8	3.2		3.2	22.5	7.0
BE11	Use transparent plastic panels behind glass windows building 2281			158	10.3		10.3	64.7	6.3
BE12	Use transparent plastic panels to replace roof skylights building 2281			118	7.7		7.7	70.4	9.2
BE13	Repair and insulate roof building 2281			372	24.2		24.2	149.6	6.2
BE14	Repair door seals, building 2370			9.6	0.6		0.6	2.0	3.2
BE15	Insulate roof in maintenance building #2226			44.8	2.9		2.9	32.8	11.3
Total	Kaiserslautern building envelope ECMS	29	2	3,702	241	70140	310.7383	1,8562,486	6.5

Note: 1 Concept BE2a is recommended as more cost effective
2 Concept BE4 is not cost effective

4.4 Kaiserslautern Compressed Air System (CA)

4.4.1 CA #1: Turn Off Air Compressors on Weekends and Nights—Building 2224

4.4.1.1 Existing Conditions

The air compressors in Building 2224 are two Kaeser CS91, running at 7.5 bars. The compressors were logged during 2 days during the assessment week. Together with measuring the current (Amps) and measuring time in loaded and unloaded mode respectively, it was observed that only one compressor was in use during those 2 days, compressor No. 2. They are probably shifted as first priority machines every week. In unloaded mode the compressor uses 48 A and when loaded 103 A. At 400 V and cos φ of 0.85 (assumed) this corresponds to 28 kW and 61 kW respectively. The machine runs approximately 50 percent loaded and 50 percent unloaded, 24 hrs/day, 7 days/week. It never shuts off completely, although (in normal conditions) no work is done at night or on weekends.

4.4.1.2 Solution

Run the compressor weekdays 0600 to 1800, or about 60 hrs/week. Shut off compressors, manually or by programmable timer with week-long function, during nights and weekends. At emergency or over-time shifts the compressors can be started manually. Check so that no equipment needs the pressure 24/7 so that no damage is caused (can be done in Phase II of the energy assessment).

4.4.1.3 Savings

By being very conservative, assuming that the compressor that is operated is running 75 percent unloaded and 25 percent loaded to cover the leaks in the compressed air system in nights and weekends, the savings from shutting the compressor off are calculated as:

Savings = (0.25 * 61 + 0.75 * 28)kW * 108hrs/week * 52 weeks = 203 MWh/yr.

Savings = 203 MWh/yr x $80/MWh = $16,200/yr (12,500 €/yr).

4.4.1.4 Investment

Programmable timer, installed and programmed: $500. Checking that the pressure is not needed by some special, sensitive equipment: $1,000, internal time. If some unique equipment needs the pressure: consider installing a separate compressor as a standalone, specific task compressor rather than keeping the entire system under pressure, see savings calculation above.

4.4.1.5 Payback Calculation

The calculated payback will occur within 2 months.

4.4.1.6 Comments

Further savings can be obtained by a systematic and policy-based effort to reduce as much of the compressed air-driven tools and machines as possible. With an overall efficiency of normally only 4 percent, the use of compressed air is the most expensive way someone can choose to perform mechanical work or operations. Electrically driven tools are much More efficient.

4.4.2 CA #2: Use Tools Operated by Electric Power Rather Than Compressed Air

4.4.2.1 Existing Conditions

Existing power tools are operated by compressed air, with pneumatic hoses strung along walls, columns, etc. Compressed air is provided by two air compressors located in a specific-use building (2224), which houses only the air compressors, and is a considerable distance away. It is known that up to 90 percent of energy used to compress air is wasted and is discharged as heat. Further, leaks in the system waste energy and can account for up to 30 percent of a compressor's output.

Based on run time of the compressors when no work is being performed, e.g., in the evenings, there is a considerable amount of air leakage in the system. See CA #2 (p 59) for additional information relative to the air compressors themselves.

4.4.2.2 Solution

Replace the pneumatic tools with electric tools. Electric tools today are actually more powerful and have more torque than typical pneumatic tools.

Further, most electric tools are now available battery-operated, with almost the same torque characteristics as electric-driven.

The one potential downside to electric tools is that they are heavier than pneumatic tools. This is beyond the scope of an energy audit and would have to be evaluated by the production staff.

4.4.2.3 Savings

Based on the above comments and the information in CA #1, there should be considerable energy and cost savings by eliminating the operation of the compressors. The calculation of the actual savings is beyond the scope of this Level 1 audit, but should be considered in a Level 2 audit.

4.4.2.4 Investment

The investment should be only the cost of the electric tools, since there should be ample electrical capacity available to handle the minimal power requirements of the electric tools, unless there were certain tools in certain areas that needed to remain pneumatic. In that case, a small air compressor could be installed in that area (or those areas).

4.4.2.5 Payback Calculation

It is estimated that the payback, if an air compressor for local specific use did not have to be installed, would be less than 1 yr. Example cost comparison for electric vs. pneumatic ½-in. impact wrench is:

- Electric $270
- Pneumatic $100.

Table 7 lists the compressed air (CA) ECM summary for Kaiserslautern.

Table 7. Kaiserslautern compressed air (CA) ECM summary.

ECM	ECM Description	Electrical Savings MmWh/yr	$k/yr	Thermal Savings MmWh/yr	$k/yr	Additional Savings $k/yr	Total Savings $k/yr	Investment $k	Simple Payback yrs
CA1	Turn Off Air Compressors on Weekends and Nights Building 2224	203	16.2				16.2	1.5	0.1
CA-2	Use tools operated by Electric Power Rather than Compressed Air							When being replaced or when buying new ones	< 1 yr

4.5 Kaiserslautern Electrical (EL)

4.5.1 EL #1: Switch Off Computers When Not in Use—Building 2233

4.5.1.1 Existing Conditions

All computers in the area are on always as IT support suggests to facilitate software updates and back-up runs. Screens are switched off for the night in offices, but in the maintenance areas, it is likely that the screens are on always.

In 2233 there are about 15 PCs with flat screens in the offices and about 20 with ordinary monitors in the maintenance areas.

4.5.1.2 Solution

Activate power-save features or switch computers off when not in use. The power saving settings will allow to switch off screen or hibernate the hard disk.

Updates and backups can be programmed to take place when the computer is switched on or during the lunch break.

4.5.1.3 Savings

The saving has been calculated assuming that a computer with 17-in. or 19-in. monitor is using 150W when the screen is on and that a PC in stand-by mode in night-time with flat screen turned off is using 50W.

The weekly power on time for the computers will be reduced from 168 hrs to 50 hrs. Savings are calculated as:

Savings = 35 x (168 – 50) hrs/week x 52 weeks/yr x 100W = 21,476kWh/yr

Savings = 21,476kWh/yr x 1KW/1,000W x $80 / MWh = $1,718 / yr (1,321 €/yr)

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.5.1.4 Investment

No investment is required; most computers already have the possibility for power saving. New advice and instructions from IT support are needed.

4.5.1.5 Payback Calculation

There will be zero payback time.

Table 8 lists the electrical (EL) ECM summary for Kaiserslautern.

Table 8. Kaiserslautern electrical (EL) ECM summary.

ECM	ECM Description	Electrical Savings MmWh/yr	$k/yr	Thermal Savings KmWh/yr	$k/yr	Additional Savings $k/yr	Total Savings $k/yr	Investment $k	Simple Payback yrs
EL1	Switch off Computers When Not In Use — Bldg 2233	36.8	2.9				2.9	0	0.0

4.6 Kaiserslautern HVAC

4.6.1 HV #1: Improve Building Heating Controls

4.6.1.1 Existing Conditions

At KAD (and Pirmasens) most of the HVAC systems are operated manually. The personnel in the buildings turn heaters on or off depending on their feelings regarding the indoor temperature. With many heaters in a big warehouse and with many persons working in the warehouse it is not likely that the heaters work uniformly to reach a normal setpoint regarding temperature. Only a few buildings have computerized, automatic control systems. and if they have, it is not certain that they work properly, see HV #240 (p 80) and HV #26 (p 101).

Thermostats are not always installed; in those cases the heaters are just switched on and off (e.g., HV #262 in Building 2281 [p 9180]). If thermostats are installed, these may be manipulated by the personnel, see HV #13, Building 2222 (p 79).

4.6.1.2 Solution

This is not to suggest a total modernization of the building heating controls; this is not the one and only solution. Modern and computerized (centralized) systems need to be maintained, supervised, and understood by the people (Federal employees or contractors) who must successfully perform the automated tasks.

However, the following, general measures are proposed:

- One or several thermostats must be installed in every building that has heaters to provide comfortable indoor temperature.
- Each thermostat shall control one or several heaters, maybe with different temperatures in different areas (might be different materials or goods that does require different conditions)
- Thermostats shall be placed in locked “cages” that can only be operated by the supervisor, who will have the key
- Thermostats should be of the kind that allows one setpoint during working hours and another at nights and weekends

4.6.1.3 Savings

Savings come from more uniform indoor temperatures, less energy wasted due to overheating to meet the comfort levels of isolated individuals, improved productivity with more even climate. It is difficult to say how big the savings are on this general level, but the proposal regarding 2222, which is specific, indicates energy savings of around 20 percent. However, every building is unique; unless temperatures and energy use are logged, it is not possible to calculate potential general savings.

4.6.1.4 Investment

Very moderate investments are necessary to gain control of the waste of energy that comes from being out of control of the important parameters, i.e., the heating of buildings and to what temperatures.

4.6.1.5 Payback Calculation

The calculated payback will occur within months (winter months).

4.6.2 HV #2: Install Exhaust Fans for Ventilation—Building 2233

4.6.2.1 Existing Conditions

One hundred and eighty employees work in Building 2233. The building was built in 1952 and has large areas of glass in the roof and the walls. During the summer the indoor temperature rises to very high levels. To reduce the indoor temperature both doors at the east and west entrances are opened, but this is not sufficient, since the building itself works as a “greenhouse.” During some days every summer (that exact number is not documented since it varies according to the outdoor temperature and the solar heat), the workers are allowed extra breaks, 2 * 15 min/day.

4.6.2.2 Solution

Either of these two solutions is proposed:

1. Install multiple exhaust fans of about 20,000 m^3/h each (12,000 cfm). With an approximate building volume of 160,000 m^3 it would probably be sufficient with 10 such exhaust fans, at the roof.
2. Install two large prop fans at the ceiling level in the east and west walls respectively, to exhaust hot air at the very ends of the building. If this is not sufficient (CFD studies could be performed to evaluate different solutions) it might become necessary also to install one or more roof exhaust fans at the centre of the building.

No matter which solution that is finally chosen, exhaust fans should be operated with at least the west and east end doors open. Exhaust fans should be temperature controlled, with respect to both indoor and outdoor temperatures. In other words, they should only be running when the outdoor temperature is higher than +20 °C AND/OR if the indoor air temperature is higher than +23 °C AND ONLY if the district heating system (and hot water circulating in the pipes) is completely shut off.

4.6.2.3 Savings

Avoiding extra breaks 20 days per summer yields calculated savings of:

Savings = 180 employees x 2 x 1/4hr x $64.8/hr x 20/yr= $116,640/yr (90,000 €)

In addition, expected savings from increased worker productivity would accrue from the improved work climate (by correcting the current “sauna” conditions), and by eliminating the extra breaks. However, measurements of increased productivity is beyond the scope of this stage of assessment.

4.6.2.4 Investment

The cost to purchase and install 10 exhaust fans with controls will be approximately $65,000 (50,000 €).

4.6.2.5 Payback Calculation

The estimated payback will occur during the first 12 hot summer days that the extra breaks are avoided (increased productivity unaccounted for).

4.6.3 HV #3: Install Destratification Fans to Recover Heat in Upper Strata—Building 2233

4.6.3.1 Existing Conditions

In Building 2233, high up at platform level close to the glass roof, there are some fans installed with the purpose to bring warm air down from the higher levels down to the working space, the occupancy zone, in the winter. Even with these fans in operation, the indoor temperature does not exceed +5 to +8 °C when the outdoor temperature is –10 °C. At 0 °C outdoors the indoor temperature reaches no more than +12 to +15 °C. Of course, these are not satisfying working conditions. The installed fans quite obviously cannot work very well, for several reasons:

- They are too small with respect to capacity (air flow) and air velocity.
- No ducts support the down-going air stream; this *might* help some, although how much is not certain.
- The installed fans do not seem to be designed for this purpose; they appear to have been taken "off the shelf" from a stock of left-over fans.

4.6.3.2 Solution

Possible solutions include:

1. Replace the existing fans with new fans, with higher design pressure and with some meters of ductwork vertically from the fan and down, just as far down as the crane allows it. The new fans must also have the capacity to transport much larger volumes of warm air down to the occupancy level than the existing ones.
2. A second alternative would be to install a Dirivent system, with a network of small dimension circular ventilation ducts (80 – 100 mm) and with nozzles at the end. This system works with very high air speed, makes large volumes of warm air eject into the jet flow from the nozzle, and moves the air around and down to the floor level.
3. A third and perhaps better alternative (if the previous measure, HV #4, is implemented) would be to use the new summer exhaust fans in the winter as well to blow air down to the floor level. Additional investment

costs will then be in the controls, in some ductwork and with automatically controlled dampers that "know" if it is summer or winter.

4.6.3.3 Savings

The savings could probably be calculated as in HV #2 [4] above, but with the extra breaks for the workers to warm up instead of cooling down and with improved productivity also in this situation where it is possible to reach more uniform, close to 18–20 °C, indoor temperature.

Also, substantial energy savings can be counted upon from not having the heaters (a total of 60 unit heaters spread over the building area) running at maximum capacity as soon as it gets cold, without ever reaching the setpoints. Since annual energy use for heat in this building alone is 7,000 MWh (over 430 kWh/m^2/yr), a good deal of money could be invested to reduce the energy bill. Regardless whether the heating system is converted to IR-heaters; the energy savings from getting the heat down from the ceiling level are enormous (savings of at least 10%):

Cost Savings: 700 MWh/yr * $65/Mwh = $45.5 K/yr

4.6.3.4 Investment

An investment in six new fans, at 20,000 m^3/h each, will cost around $40,000, installed with controls. Additional investment in case the summer exhaust fans are installed: $20,000 (15,000 €)

4.6.3.5 Payback Calculation

$40,000/ $45,500/yr = 0.9 yrs

4.6.3.6 Comments

The existing fans must be removed. They can be used in another building, with lower ceiling. An example would be in a warehouse like 2371 or 2281 where it is also likely that warm air can be transported from the ceiling down to the occupancy zone.

The study of the Kieback & Peter HVAC control system showed that space temperature in Building 2233 is measured at floor level and at the ceiling level. With an outdoor temperature of +12.5 °C the average temperature at floor level was +18 °C and the temperature at the ceiling level (uncertain on at what height the temperature sensors are placed) were at an average of over +27 °C. This indicates that transporting warm air from the ceiling level to the occupancy zone really has a great potential and that this proposal makes sense.

4.6.4 HV #4: Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers #1 to #3

4.6.4.1 Existing Conditions

The are four test stands in Building 2233 that are used to test engines to be installed into Humvee vehicles. Each test lasts about 2 hrs. Cooling water from a cooling tower is used to cool the dynamometer brake and the engine radiator. Energy is also exhausted outside in the hot combustion gases. The annual fuel consumption is 460 MWh/yr for the four test cells, which if divided by 240 working days gives a fuel use per day of 1.9 MWh/day. The theoretical fuel input capacity for a Humvee motor is around 900 kW, the test uses about 92 percent of this use. For a Humvee diesel engine, approximately 60 kW is directed to the radiator, 180 kW is consumed by the brake and 200 kW of energy goes up with the exhaust gases. The rate of energy use of 440 kW/hour suggests the dynamometer are testing about 50 percent of the time.

For three of the dynamometers there is a heat recovery unit that uses the radiator heat to heat air that is blown into the building (Figure 9). This unit is not used much due to the noise made when in operation. The fourth dynamometer sends all its waste heat to a cooling tower for removal.

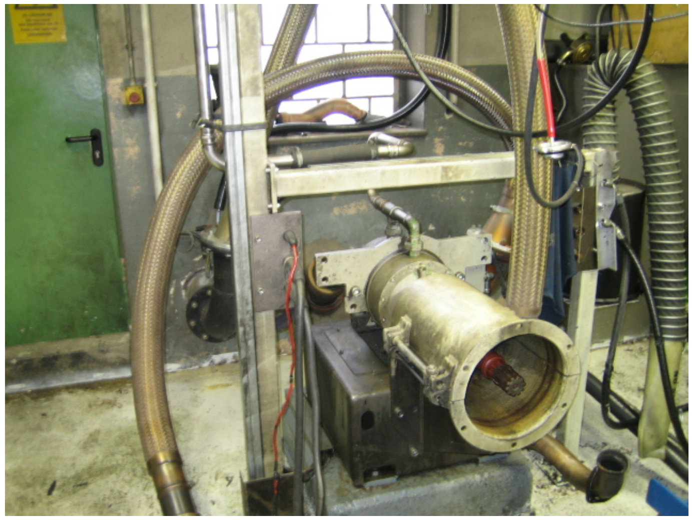


Figure 9. Dynamometer waste heat recovery unit in Building 2233.

4.6.4.2 Solution

About 10 percent heat is released from dynamometer operations to the room by convection and radiation losses; the other 90 percent is evenly divided between work to the brake, exhaust gases, and heat removed by the radiator water. The total annual value of the fuel consumed is $29,900. This implies that there is a waste heat flow of approximately $9,000 in the exhaust gases , radiator water, and brake cooling water. If there is a use of this heat for half a year and 60 percent is obtainable from the waste stream, this represents an energy savings of $2,700/yr.

To recover heat from the exhaust gases, four heat recovery units would be required each about 3,000 CFM, for which the cost of each would approach $20,000 installed. This provides an unfavorable payback of almost 30 yrs.

The only practical project to recover some of this energy is to use the existing heat recovery system that has the noise problem. The air discharge of the unit could be reconfigured by adding more duct to act as a silencer and blow the tempered air into the building at another location. The fans could also be changed if necessary.

4.6.4.3 Savings

Recovery of heat from the radiator water can be a benefit for half the year. This heat recovery unit services three of the four dynamometers. It is estimated 70 percent of the available heat is recoverable. The resulting savings is $2,360 (1,800 €)/yr. Savings are calculated as:

Energy cost savings = $9,000 X 0.5 X 0.75 X 0.7 = $2,360/yr.

Energy savings = $2,360/ $65/MWH = 36.3 MWHth/yr

4.6.4.4 Investment

The cost to accomplish the modifications to the existing heat recovery unit should not exceed $12,000 (9,200 €).

4.6.4.5 Payback Calculation

The simple payback is 5.1 yrs.

4.6.5 HV #5: Replace Heating System for the Hot Water Radiant Heating Sys-Tem in Maintenance Building #2233, Kaiserslautern

Heat exchanger station and main distribution are in good conditions.

4.6.5.1 Problem

Inefficient heating during winter time. Secondary hot water distribution system is very old, and its left side is not insulated. Some very old air heaters are used and connecting pipes to some of them are not insulated.

4.6.5.2 Solution

Replace warm air heaters with hot water radiation panels. Install central controls of magnetic valves for the secondary hot water distribution system. Insulate hot water piping.

4.6.5.3 Estimated Energy Savings and Costs

Area: 14,900 m^2

Heating: 6,060 MWh

Energy savings per year: 25%

Energy costs: $65/MWh

4.6.5.4 Savings

6,060 MWh * 25% * $65/MWh = $98,475/yr

4.6.5.5 Cost

Installation of heat radiator panels

Panels 745 pieces (3m length) * $525/panel = $391,125
Piping 1,000 m * $62.5/m = $62,500
Design $1,250/d * 5d= $6,250
Total Cost: $459,875
Payback: $459,875/ $98,475/yr = 4.7 yrs

4.6.6 HV #6: Reduce Excessive Air Use—Welding and Vehicle Exhaust Building

4.6.6.1 Existing Condition

The exhaust fans for the welding and vehicle exhaust areas run continuously during all shifts, even when there is no requirement for them to be in use.

4.6.6.2 Solution

Install dampers at individual stations to reduce the amount of total system air required when those stations are not in use. Install variable speed drives (VSD) at each exhaust fan, which would sense lower airflow requirement by means of signals from pressure sensors. VSD will then slow fans down to meet new airflow and pressure requirements. Exhaust air would always be available, as fans would be continuously running during all shifts, but the fans would be using only as much energy as would be required for the amount of exhaust air needed at any particular time.

4.6.6.3 Savings

The energy used by a variable torque fan varies as the cube ratio of the speed. As a fan slows down, the energy use decreases by $(rpm1/rpm2)^3$. Thus, if only half the air is required at a particular time, the energy used by the fan would theoretically be $(1/2)^3$, or 1/8 the original power.

In actuality, because of windage, bearing, and inertia losses, this number is closer to 20 percent than 12.5 percent, but is still a considerable energy and cost saving.

Using the example of a 20 HP motor, and assuming the air requirement during an 8-hr shift would be 40 percent on the average, the energy used by the fan would theoretically be 0.40^3, or 0.06 of the full load energy. In actuality, it would be more like 0.10. Savings are calculated as:

The energy use for the 20 HP motor in this example, assuming the existing motor is 80% loaded, would be 20 hp x 0.80 x 0.746 kW/hp x 16 hrs/day x 250 days/yr = 47,744 kWh/yr

The energy use with a VSD would be 0.1 x 0.746 x 16 x 250 = 298 kWh/yr

The energy savings would be 47,744 – 298 = 47,446 kWh/yr.

The energy cost savings would be 47,446 kWh/yr x $0.08 / kWh = $3796 / yr.

4.6.6.4 Investment

The size of all exhaust fan motors in use at the time of this audit were not ascertained. Using a 20 HP motor as an example, the installed cost of a VSD to replace the existing starter and disconnect would be approximately $3500. Assuming that an average of four dampers are required for each exhaust system, the installed cost would be approximately $4000 for the dampers and controllers.

4.6.6.5 Payback Calculation

The calculated payback will occur in:

$7500/$3796 = 2.0 yrs

4.6.7 HV #7: Replace Warm Air Heaters with Hot Water Radiant Panels at Warehouse, Building #2213

The roof and walls are well insulated.

4.6.7.1 Problem

Warm air heaters are not efficient.

4.6.7.2 Solution

Replace warm air heaters with hot water radiation panels.

4.6.7.3 Estimated Energy Savings and Cost

Area: 950 m^2

Heating: 380 MWh.

Energy savings per year: 25%

Energy costs: $65/MWh

Saving: 380 MWh * 25% * $65/MWh = $6,175/yr

4.6.7.4 Cost

Installation of heat radiator panels

Panels 48 pieces (3m length) * $525/panel = $25,200

Piping 60m * $62.5/m = $3,750

Design $1,250/d * 4d= $5,000

Total cost: $33,950

4.6.7.5 Payback

$33,950/ $6,175/yr = 5.5 yrs

4.6.8 HV #8: Replace Warm Air Heaters with Hot Water Radiant Panels at Warehouse, Building #2219

Roof and walls are well insulated.

4.6.8.1 Problem

- Warm air heaters are not efficient.
- Ventilation flaps and facade are not tied

4.6.8.2 Solution

- Replace warm air heaters with hot water radiation panels
- Install new flaps

4.6.8.3 Estimated Energy Savings and Cost

Area: 3,040 m^2

Heating: 960 MWh.

Energy savings per year: 25%

Energy costs: $65/MWh

Saving: 960 MWh * 25% * $65/MWh = $15,600/yr

4.6.8.4 Cost

Installation of heat radiator panels:

Panels 152 pieces (3m length) * $525/panel = $79,800
Piping 190 m * $62.5/m = $11,875
Design $1,250/d * 5d= $6,250
Total cost: $97,925

4.6.8.5 Payback

$97,925/ $15,600/yr = 6.3 yrs

4.6.9 HV #9: Recirculate Exhaust Air Back into Booth during Drying Operations—Building 2225

4.6.9.1 Existing Conditions

The main paint booth located in Building 2225 uses 100 percent outside when ever it is operating. In the winter time, this air must be heated to 70 °F (21 °C) for a proper paint and drying temperature. Outside air is needed when parts are being painted and during the flash-off period after painting to keep the solvent fumes under control, but during the part drying period in the booth, there is little solvent being released to the atmosphere and most of the exhaust air can be recirculated.

4.6.9.2 Solution

To achieve this recirculation of oven air place, a new duct between the exhaust air discharge duct and the air intake to the booth's supply air units. There will be dampers placed in the new connection duct as well as after the connection in the exhaust duct. When the paint booth's operation switches to drying, the damper in the exhaust duct will partially close and the damper in the connect duct will open allowing 70 percent of the exhaust air to be recirculated.

4.6.9.3 Savings

The estimated air flow in this paint booth is 24,000 CFM, which can be recirculated an estimated 15 hrs/wk or 360 hrs during the heating season each year. The estimated heating energy savings is 59 MWh/yr. Savings are calculated as:

Q= 1.08 X 24,000 CFM X 70% (70 – 39) °F X 360 hrs/yr/ 3413 MWH/Btuh
= 59 MWHth

Energy cost savings = 59 MWHth X $65/MWHth = $3,856/yr (2,970 €)

4.6.9.4 Investment

The estimated cost of the new dampers and duct connections is $20,000 (15,400 €).

4.6.9.5 Payback Calculation

The resulting payback is 5.2 yrs.

4.6.10 HV #10: Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2238

4.6.10.1 Problem

Warm air heaters are not efficient. Excessive heat losses due to poor roof insulation. Central heating heat exchange station is over sized for this building

4.6.10.2 Solution

- Replace warm air heaters with hot water radiation panels
- Insulate roof
- Use heat exchanger station for other buildings
- Replace heating system

4.6.10.3 Estimated Energy Savings and Cost

Area: 1,850 m^2

Heating: 540 MWh

Energy savings per year: 25%

Energy costs: $65/MWh

4.6.10.4 Savings

540 MWh * 25% * $65/MWh = $8,775/yr

4.6.10.5 Cost

Installation of Heat Radiator Panels

Panels 92 pieces (3m length) * $525/panel = $48,300

Piping 110 m * $62.5/m = $6,875

Design $1,250/d * 5d= $6,250

Total cost: $61,425

4.6.10.6 Payback

$61,425/ $8,775/yr = 7.0 yrs

4.6.10.7 Insulate Roof

<u>Estimated Energy Savings and Cost</u>

Existing insulation: u = 2 W/m²K

New insulation: u = 0.5 W/m²K

Area: 1,850 m²

Mean outside temperature: 4 °C

Use: 8 h/d ; 5 d/w ; 200 d/yr = 1,140 h/yr

Energy costs: $65/MWh

Energy loss with existing insulation: 2 W/m²K * 1,850 m² * (20-4) K * 1,140 h/yr = 67.5 MWh/yr

Energy loss with a new insulation: 0.5 W/m²K * 1,850 m² * (20-4) K * 1,140 h/yr = 16.9 MWh/yr

Savings: (67.5 – 16.9) MWh/yr * $65/MWh = $3,289/yr

<u>Cost</u>

Cost of insulation: $20/m² * 1,850 m² = $37,000

<u>Payback</u>

$37,000/ $3,289/yr = 11.2 yrs

4.6.11 HV #11: Replace Heaters and insulate the roof In Warehouse, Building # 2239, Kaiserslautern

4.6.11.1 Problem

Warm air heaters are not efficient. Excessive heat losses due to poor roof insulation.

4.6.11.2 Solution

Replace warm air heaters with hot water radiation panels,

Insulate Roof

Connect the building to he central hot water system, e.g., to the existing heat exchange station at the building #2238.

Estimated Energy Savings and Cost

Heating System Replacement

Area: 2,780 m^2

Heating: 830 MWh.

Energy savings per year: 25%

Energy costs: $65/MWh

Saving: 830 MWh * 25% * $65/MWh = $13,488/yr

Cost

Installation of heat radiator panels

Panels 139 pieces (3m length) * $525/panel = $72,975

Piping 170 m * $62.5/m = $10,625

Design $1,250/d * 5d= $6,250

Total cost: $89,850

Payback

$89,850/ $13,488/yr = 6.7 yrs

Roof Insulation

Estimated energy savings and cost

Old insulation: u = 2 W/m^2K

New insulation: u = 0.5 W/m^2K

Area: 2,780 m^2

Mean outside temperature: 4 °C

Use: 8 h/d ; 5 d/w ; 200 d/yr (= 1,140 h/yr)

Energy costs: $65/MWh

Energy losses with existing insulation: 2 W/m^2K * 2,780 m^2 * (20-4) K * 1,140 h/yr = 101.4 MWh/yr

Energy losses with new insulation

0.5 W/m^2K * 2,780 m^2 * (20-4) K * 1,140 h/yr = 25.4 MWh/yr

Savings: (101.4 – 25.4) MWh/yr * $$65/MWh/yr= $4,940/yr

Cost

Cost of $insulation:

20/m^2 * 2,780 m^2 = $55,600

Payback

$55,600/ $4,940/yr = 11.3 yrs

4.6.12 HV #12: Improve System Efficiency in Tire Repair and Masking Area—Building 2255

4.6.12.1 Existing Conditions

The existing H&V units in this area are not operational, leading to lack of air movement all year and lack of heat in the cold weather. Because of this, additional time is required to mask and prepare vehicles before they enter the paint booth.

4.6.12.2 Solution

Two solutions were examined: radiant heating panels and repair of the existing systems. Radiant heating panels would be a more energy efficient way to provide heat in the cold weather; however, that type of system would do nothing to provide any air movement in the cooling season to make the workers more comfortable because of the evaporative cooling effect provided by air movement, which would make them more productive.

It was therefore decided that repair of the existing units and the ductwork, since they are already in place would be a more advantageous solution. Researchers could not discover why the existing units and ductwork had been decommissioned. The reasoning for this needs to be ascertained before a final decision is made.

4.6.12.3 Savings

The savings will occur in the increase in productivity, both from the personnel having to take fewer breaks in both the cold and hot weather, and from the decreased time to prepare vehicles to enter the paint booth. What this increase in productivity might be is beyond the scope of this study.

4.6.12.4 Investment

The cost of the retrofit is unknown without further study.

4.6.13 HV #13: Place Thermostat Controls Away from Occupants for Improved Control for Air Heaters—Building 2222

4.6.13.1 Existing Conditions

The research team noticed that it was very warm inside Building 2222. When two of the thermostats that control the unit heaters (supply from the district heating network) were checked, it was found that one thermostat had a setpoint of +24 °C both night and day and the second had a setpoint of +24 °C in daytime and +20 °C at night. The normal setpoint would be +20 °C during working hours and a lower setting, perhaps +17 °C at night and weekends. Heating the building to +24 °C wastes energy. The supervisor stated that the setpoint is supposed to be +20 °C in daytime.

4.6.13.2 Solution

Thermostats must be adjusted to both day- and nighttime setpoints. Locks should be purchased and installed so that only the supervisor can change the setpoints. This will prevent energy waste.

4.6.13.3 Savings

Building 2222 is approximately 1,400 m^2 (15,000 sq ft). With a normal annual energy use of around 300 kWh/m^2 this means 420 MWh of district heating per year. By reducing the indoor temperature from +24 °C to +20 °C in daytime and to +18 °C in nights and weekends approximately 25 percent of the annual energy use can be saved, or 105 MWhth/yr worth $6,800/yr (5,200 €/yr).

4.6.13.4 Investment

The required investment will be no more than $200 (150 €).

4.6.13.5 Payback Calculation

The calculated payback will occur within days.

4.6.13.6 Comments

Since it is uncertain whether the thermostat settings observed by the research team represent the settings in operation for the entire winter, the calculated savings must be seen as “what if” calculations. However, the fact that such easy, “low hanging fruits” are available indicates that KAD personnel could improve attention to and awareness of energy costs.

4.6.14 HV #14: Increase Ventilation To Reduce Solvent Fumes in Space—Building 2222

4.6.14.1 Existing Conditions

In Building 2222 there is little ventilation air brought into the building and solvent fumes from cleaning transmission parts is very noticeable. Transmissions are tested in this building by placing them on a test stand that needs cooling to operate. At first glance it was thought that the heat being dissipated could be used to warm ventilation air to the building, but the quantity of heat is small and intermittent making it impractical for an energy source.

4.6.14.2 Solution

A ventilation unit having a heat exchanger could be installed to reduce the concentration of solvent fumes. Air would be exhausted through this unit and the heat in the warm exhaust air could be transferred to the incoming supply air.

4.6.14.3 Savings

There would be no energy savings with this project, but the workspace environmental condition would improve. The result may be a reduction in worker complaints and use of sick time. More evaluation of the conditions would be required to determine the extent.

4.6.14.4 Investment

The cost for a 10,000 CFM supply air unit with a heat recovery unit and a hot water coil would be about $40,000 (30,800 €).

4.6.14.5 Payback Calculation

There is no economical payback that can be determined, but the installation should be justified by the improved workspace conditions.

4.6.15 HV 15: Replace Warm Air Unit Heaters with Hydronic Radiant Panels Heaters in Paint Shop, Building # 2225

Building is connected to district heating.

4.6.15.1 Problem

Low efficiency of heating with unit air heaters

4.6.15.2 Solution

Replace warm air unit heaters with hot water radiant panels

4.6.15.3 Estimated Energy Savings and Cost

Area: 920 m^2
Heating energy used: 270 MWh
Energy savings per yr: 25%
Energy costs: $65/MWh
Saving: 270 MWh * 25% * $65/MWh = $4,388/yr

4.6.15.4 Cost

Installation of heat radiator panels

Panels 45 pieces (3m length) * $525/panel = $23,625

Piping 50 m * $62.5/m = $3,125

Design $1,250/d * 4d= $5,000

Total Cost: $31,750

4.6.15.5 Payback

$31,750/ $4,388/yr = 7.2 yrs

4.6.16 HV #16: Provide Heaters over Doors on South Side—Building 2226

4.6.16.1 Existing Conditions

Building 2226 is used for large vehicle maintenance repair. These large vehicles enter the building through doors on the south side of the building. There are no door heaters to reduce the flow of outside air when these doors are opened. Also, the building heating system is not very effective since the heaters are located high in the building and have difficulty getting the warm air down to worker level.

4.6.16.2 Solution

Install two door heaters that can direct warm air down over the door opening when a door is raised. This will reduce the cold in the building when a door is opened.

4.6.16.3 Savings

There is no measurable energy savings with this system, but occupant comfort should be improved.

4.6.16.4 Investment

The cost for two door heaters should be about $100,000 (76,900 €).

4.6.16.5 Payback Calculation

There is no economical payback that can be determined, but the installation should be justified by the improved workspace conditions.

4.6.17 HV #17: Replace Warm Air Unit Heaters with Hydronic Radiant Panels Heaters in Maintenance Building # 2226

Heating system is connected to the district heating.

4.6.17.1 Problem

Low efficiency of heating with unit air heaters

4.6.17.2 Solution

Replace warm air unit heaters with hot water radiant panels

4.6.17.3 Estimated Energy Saving and Costs

<u>Heaters Replacement</u>

Area: 1,640 m^2
Heating: 480 MWh.
Energy savings per yr with unit heaters replacement: 25%
Energy costs: $65/MWh
Saving: 480 MWh * 25% * $65/MWh =$7,800/yr

<u>Cost of Radiant Panels Installation</u>

Panels 80 pieces (3m length) * $525/panel = $42,000
Piping 100 m * $62.5/m = $6,250
Design $1,250/d * 5d= $6,250
Total cost: $54,500

<u>Payback</u>

$54,500/ $7,800/yr = 7.0 yrs

4.6.18 HV #18: Separate the Building Heating System from the Boiler and Connect the Building to District Heating System at Apprentice Shop, Building # 2364

4.6.18.1 Problem

Oversized oil heated boiler providing a low pressure steam for the building.

4.6.18.2 Solution

Separate the building heating system from the oil heated boiler and connect the building system to the district heating.

No information on energy consumption was available. Estimated energy savings: 25% by switching to district heating. Expected payback period is less than 5 yrs.

4.6.19 HV #19: Replace Warm Air Heaters with Hot Water Radiant Panels Replace Heaters in Apprentice Shop, Building # 2363

4.6.19.1 Problem

Inefficient heating during winter time.

4.6.19.2 Solution

Replace warm air heaters with hot water radiation panels.

<u>Estimated energy savings and cost:</u>

Area: 1,150 m^2
Heating: 300 MWh
Energy savings per yr: 25%
Energy costs: $65/MWh
Saving: 300 MWh * 25% * $65/MWh = $4,875/yr

<u>Installation of Heat Radiator Panels</u>

Panels 57 pieces (3m length) * $525/panel = $29,925
Piping 70 m * $62.5/m = $4,375
Design $1,250/d * 4d= $5,000
Total cost: $39,300

<u>Payback</u>

$39,300/ $4,875/yr = 8.1 yrs

4.6.20 HV #20: Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop, Building # 2372

4.6.20.1 Problem

Warm air heaters are used in combination with ventilation system. Additional need for mobile air heaters.

4.6.20.2 Solution

Re-commission existing ventilation system Replace warm air heaters with hot water radiant panels

4.6.20.3 Estimated Energy Savings and Cost

Area: 1,600 m^2
Heating: 760 MWh.
Energy savings per yr: 25%
Energy costs: $65/MWh
Saving: 760 MWh * 25% * $65/MWh = $11,400/yr

4.6.20.4 Cost

Installation of heat radiator panels:

Panels 80 pieces (3m length) * $525/panel = $42,000
Piping 100 m * $62.5/m = $6,250
Design $1,250/d * 4d= $5,000
Total cost: $53,250

4.6.20.5 Payback

$53,250/ $11,400/yr = 4.7 yrs

4.6.21 HV #21: HV #22 [16]: Have Heating Utility Turn Off Heat to Buildings when not Warranted

4.6.21.1 Existing Conditions

It was apparent that many of the buildings were being heated unnecessarily by district heat because of a short cool spell that happened during the site visit. It may very well be that the district heating is in use on many occasions when it is not warranted.

4.6.21.2 Solution

Make sure that main heating valves are closed when heat to a building or an area is not required.

4.6.21.3 Savings

Actual savings will depend on the situation.

4.6.21.4 Investment

There is no investment required. Someone needs to be given the responsibility to decide whether or not heat is required, and to ensure it is not on when not required.

4.6.21.5 Payback Calculation

The calculated payback is immediate.

4.6.22 HV #22: Use Heat from Generator Test for Building Heat—Building 2362

4.6.22.1 Existing Conditions

Building 2362 is used to test portable electrical generators and in doing so needs a way to use the electricity created. This is done by heating up electrical coils in an air flow system. Air is passed through the electrical coils to cool them. In this system, outside air is passed through the system and discharged outside (Figure 10) with no benefit gained from this waste heat. Two systems (one at 500 kW, the other at 10 kW) perform this function.

Figure 10. Cooling system pumps and cooling tower in Building 2362.

4.6.22.2 Solution

The heat provided by the electric heating coil could be used by the building during the winter. This could be accomplished by adding a duct section that would redirect the heated air back into the building. Dampers would be installed to adjust the amount of heated air that would enter the building.

4.6.22.3 Savings

Using the 500 kW heating unit as the major heating source and assuming its loaded at 30 percent for half the time, savings are calculated as:

Q= 500 kW X 0.5 X 0.3 X 40 hrs/ week X 26 weeks / yr = 78,000 kWh/yr

Cost savings = 78 MWHth X $65/MWH = $5,070/yr (3,900 €)

4.6.22.4 Investment

The cost for the duct extensions, an opening into the building and dampers with controls is approximately $15,000 (11,500 €).

4.6.22.5 Payback Calculation

The resulting payback period is 3 yrs.

4.6.23 HV #23: Provide Door Heater at Door on East Side—Building 2371

4.6.23.1 Existing Conditions

Building 2371 is used to ship parts for the Depot and it is occupied 24 hrs/day 7 days/week. Parts are gathered and taken to this building and assembled in their shipping containers for placement in a trailer. The trailers are stationed at shipping docks, which are open to the outside. The major dock can handle a number of trailers and thus the door opening into the building receives much fork truck traffic.

This door is open approximately 25 percent of the time to let a fork truck in or out. When open cold outdoor air enters the building creating cold drafts and making the space uncomfortable.

A vestibule is not considered for this application since the truck dock floor is a metal grading with many openings. There is also little room to place a vestibule structure and still maneuver fork trucks to all trailer locations.

4.6.23.2 Solution

Place a door heater at this door to reduce the outside air that enters the building. This door heater will also temper the air that does enter the building through the door.

4.6.23.3 Savings

The addition of a door heater on this door will reduce the amount of cold air entering the building. There will be an estimated 3,000 CFM reduction in the infiltration of outside air that would require heating. Savings are calculated as:

Q= 1.08 X 3,000 CFM X 25% (64.4 – 39) °F X 6000 hrs/yr/ 3413 MWH/Btuh = 36 MWHth

Energy cost savings = 36 MWHth X $65/MWHth = $2,351/yr (1,810 €)

4.6.23.4 Investment

The approximate cost for a 12,000 CFM heater for this 10 x 12-ft door is $25,000 (19,200 €).

4.6.23.5 Payback Calculation

The resulting payback is 10.6 yrs.

4.6.24 HV #24: Provide Better Controls of H&V—Building 2371

This ECM has partly been discussed with Dieter Haertel, who expressed the belief that the control system works as it should in Building 2371. Nevertheless, the function of the system should be thoroughly checked, either in a Phase II assessment or by the system provider in teamwork with DPW and with the occupants of the building (that know how the indoor climate varies).

4.6.24.1 Existing Conditions

The heating and ventilation control system in the 2371 warehouse requires attention. Apparently, inaccurate information has been used to justify continuously running the AHUs (six air handlers at 33,500 m^3/h each) on the basis that workers occupy the Building 24/7. In fact, only three people work the night shift, in the south section of the building—not justification to run the AHUs in the other two thirds of the building.

It was observed that the two AHUs in the northern section of the building were not running although this area was the coldest and where they were in most need for heat. On the other hand, in the other parts of the building the AHUs were running, although the indoor temperature had reached the various setpoints (as measured by us and as identified from the computer screen of the Kieback & Peter HVAC control system).

Apparently, temperature sensors have been mixed so that the AHUs operate on faulty signals, which do not correspond to the space they should heat and to ventilate.

The system clock was 1 hour wrong, which is immaterial for 24/7 operation. However, for more efficient operation (i.e., running only Section 3 24/7, and the other AHUs on weekdays 0500–1700 (unless for heating when a minimum night temperature of, say, +15 °C is reached), the clock must adjusted to reflect the correct time.

4.6.24.2 Solution

1. Check the function of the heating and ventilation controls. Make sure that they work properly
2. Consider controlling the supply air temperature according to measured exhaust air temperature, with supply air temperature on a curve between a maximum and a minimum temperature.
3. Run only two AHUs in Section 3 at night and on weekends. Run the remaining four AHUs only when needed to maintain a minimum temperature, at 100 percent return air, at night and on weekends.

4.6.24.3 Savings

The heat consumption in Building 2371 is 2,500 MWh/yr. That is approximately 250 kWh/m^2,yr. Minimizing the ventilation flow as suggested above, and night and weekend heating to only +15 °C, will save 365 MWh of electricity worth $29,000/yr and 600 MWh of district heat worth $39,000/yr, totally $68,000/yr (52,000 €/yr).

4.6.24.4 Investment

The required investment will include engineering time to check the controls, new controls to implement solution #2 and #3.

4.6.24.5 Payback Calculation

The calculated payback will occur immediately.

4.6.25 HV #25: Insulate Heating System Components—Building 2371

4.6.25.1 Existing Conditions

The district heating network enters at the south west corner of Building 2371. After the heat exchangers, some uninsulated pipes lead to unnecessary heat losses in the secondary system, and also to unnecessary high local temperatures due to heat losses from radiation and convection.

4.6.25.2 Solution

Insulate both supply and return pipes.

4.6.25.3 Savings

Since the size of the uninsulated part of the system is unknown, savings in this case cannot be calculated.

4.6.25.4 Investment

The required investment will be a few hundred dollars.

4.6.25.5 Payback Calculation

The calculated payback will occur within 2 yrs.

4.6.26 HV #26: Provide Temperature Control of Unit Heaters—Building 2281

4.6.26.1 Existing Conditions

Building 2281 is a warehouse with an area of approximately 6,000 m^2 (70,000 sq ft). The building is heated by a large number of unit heaters, supplied from the district heating network. The district heating comes in at the east end and goes all the way to the west end, after which it is distributed in the secondary system to all the unit heaters.

One of the most urgent problems to solve in this building (after the poor roof) is to correct the controls for the unit heaters. (They are currently switched on or off manually.)

4.6.26.2 Solution

At least six thermostats must be installed in the building. Each thermostat shall control a group of unit heaters, possibly with different temperatures in different areas (might be different materials or goods that does require different conditions). Thermostats shall be placed in locked "cages" that can only be operated by the supervisor, who will have the key.

Thermostats should be programmable, to allow one setpoint during working hours and another at night and on weekends. This will create uniform and stable space temperatures and a good working environment

4.6.26.3 Savings

Because no recorded or logged data on indoor temperatures in the winter was available, savings for these improvements are hard to calculate. However, experience suggests that this kind of measure generally saves 10 percent of the heat consumption over a year. For Building 2281, assuming heat consumption in the region of 300 kW/m²,yr (between the numbers of buildings 2371 and 2233), the savings then would be 180 MWhth/yr, or about $11,700/yr (9,000 €/yr)

4.6.26.4 Investment

The required investment will be about $7,000 (5,000 €)

4.6.26.5 Payback Calculation

Payback will occur within 7 months.

Table 9 lists the HVAC ECMs for Kaiserslautern.

Table 9. Kaiserslautern AD HVAC ECM summary.

		Electrical Savings		Thermal Savings		Additional Savings	Total Savings	Investment	Simple Payback
ECM	ECM Description	MWh/yr	$K/yr	MWh/yr	$K/yr	$K/yr	$K/yr	$K	yrs
HV1[1]	Improve Building Heating Controls								
HV2	Install Exhaust Fans To Ventilate Building 2233					116.64	116.6	65.0	0.6
HV3	Install Destratification Fans Recover Heat in Upper Strata – Building 2233			700	45.5		45.5	40.0	0.9
HV4	Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers 1 to 3			36.3	2.4		2.4	12.0	5.1
HV5	Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2233,			6.06	98.5		98.5	459.9	4.7
HV6	Reduce Excessive Air Use in Welding and Vehicle Exhaust Building 2233	46.4	3.7				3.7	7.5	2.0
HV7	Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,			95.0	6.2		6.2	33.95	5.5
HV8	Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,			24.0	15.6		15.6	97.9	6.3

		Electrical Savings		Thermal Savings		Additional Savings	Total Savings	Investment	Simple Payback
ECM	ECM Description	MWh/yr	$K/yr	MWh/yr	$K/yr	$K/yr	$K/yr	$K	yrs
HV9	Recirculate Exhaust Air Back into Booth During Drying Operations, Building 2225			59	3.8		3.8	20.0	5.2
HV10	Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2238			185.6	12.06		12.06	98.42	8.2
HV11	Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2239			283.5	18.43		18.43	145.5	7.9
HV12[2]	Improve System Efficiency in Tire Repair and Masking Area-Building 2255								
HV13	Place Thermostat Controls Away From Occupants. Improved Control For Air Heaters	105	8.4				8.4	0.2	0.02
HV14[3]	Increase Ventilation to Reduce Solvent Fumes in Space-Building 2222							40	
HV15	Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop Building 2225			76.5	4.4		4.4	31.75	7.2
HV16[4]	Provide Heaters over Doors on South Side-Building 2226							100	
HV17	Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2226			120	7.8		7.8	54.5	7.0
HV18	Separate the Building Heating System from the Boiler and Connect the Building to District Heating System at Apprentice Shop, Building # 2364			~25%	~25%				< 5 yrs
HV19	Replace Warm Air Heaters with Hot Water Radiant Panels in Apprentice Shop, Building # 2363			75	4.9		4.9	39.3	8.1
HV20	Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop, Building # 2372			190	11.4		11.4	53.25	4.7
HV21	Have Heating Utility Turn off Heat to Buildings when not Warranted								Immediate
HV22	Use Heat from Generator Test for Building Heat, Building 2362			78	5.1		5.1	15.0	3.0
HV23	Provide Door Heater at Door on East Side of Building 2371			36	2.3		2.3	25.0	10.7

		Electrical Savings		Thermal Savings		Additional Savings	Total Savings	Investment	Simple Payback
ECM	ECM Description	MWh/yr	$K/yr	MWh/yr	$K/yr	$K/yr	$K/yr	$K	yrs
HV24	Provide Better Controls Of H&V In Building 2371	365	29.2	600			29.2		0.0
HV25	Insulate Heating System Components-Building 2371								< 2 yrs
HV26	Provide Temperature Control Of Unit Heaters In Building 2281		0.0	180	11.7		11.7	7	0.6
Total	Kaiserslautern HVAC ECMs	516	41	989	25	0	67	87	1.3

Note: 1 HV1 Requires moderate investments resulting in up to 20% thermal energy savings with the payback within one heating season
2. This ECM will result in productivity improvement in summer and winter seasons. Requires further study with support from the shop management
3. Implementation of this ECM doesn't have economical justification but is strongly recommended for safety and health reason
4. Implementation of this ECM doesn't have economical justification but is strongly recommended for workers comfort reason

4.7 Pirmasens Building Envelope (BE)

4.7.1 BE #16: Install Drop Ceiling in Certain Spaces—Building 4000

4.7.1.1 Existing Conditions

Building 4000 is a tall building with a number of rooms used to perform functions associated with vehicle repair. Some of these areas are served by overhead cranes that need the high space. Other spaces could function well with a much lower ceiling (Figure 11). With a lower ceiling less heat would be needed to maintain room temperatures in the winter. This applies to the wood shop, transmission repair, and an adjacent space to transmission repair. The total area of these spaces is 3,266 sq ft, approximately 2.6 percent of the total building area.

Figure 11. Drop ceiling in Building 4000.

4.7.1.2 Solution

In the spaces that are narrow enough to support a ceiling without interim supports install a new ceiling at a height of approximately 12 ft. This will require a new lighting system, new air diffusers attached to extended ducts tied to the supply and return air systems as well as new ceiling frames and panels. Some of these panels should be transparent to allow light from the skylights above to pass through. The skylights are also operable to allow venting of warm air during the economizer cooling cycle.

4.7.1.3 Savings

It is estimated that dropping the ceiling will save 25 percent of the heat that would be required for these spaces. The total annual heating use for the building is 3,303 MWHth:

Q = 3,303 MWH X 0.026 X 0.25 = 21.5 MWHth

Cost Savings = 21.5 MWHth X $65/MWH = $1,397/yr (1,700 €)

4.7.1.4 Investment

The estimated cost for a new ceiling is $10/sq ft or $32,660 (25,100 €).

4.7.1.5 Payback Calculation

The payback for this project is 23 yrs and thus is not recommended.

4.7.2 BE #17: Close Opening above Crane Using Brushes and Rubber Strips—Building 4000

4.7.2.1 Existing Conditions

In Building 4000 the crane in the middle section of the building can move outside to pick up vehicles or parts that need to be brought inside for repair. When the crane is required to be moved outside, a section of the upper portion of the building is lifted up to allow the crane carriage to pass through the outside wall. Above the two crane rails there are small openings to allow the crane wheels to pass. There is no building component that move into this space to seal these opening so no cold air can enter during the winter.

4.7.2.2 Solution

Place rubber flaps or long brush fibers in these spaces to close off the openings.

4.7.2.3 Savings

It is estimated that closing these openings will reduce the infiltration by 400 CFM. This will provide an energy savings of 19 MWHth/yr.

> Q= 1.08 X 400 CFM X (64.4 – 39) °F X 6000 hrs/yr/ 3413 MWH/Btuh = 19 MWHth
>
> Energy cost savings = 19 MWHth X $65/MWHth = $1,254/yr (965 €)

4.7.2.4 Investment

The cost to install this rubber flab or brushes is estimated to be $400 each or $1600 (1,230 €) for all four openings.

4.7.2.5 Payback Calculation

The resulting payback is 1.3 yrs.

4.7.3 BE #18: Close Openings in Carpenter Storage Room—Building 4000

4.7.3.1 Existing Conditions

In the storage room above the carpenter shop there are several holes in the outside wall that were required by a previous system that has been removed. These openings allow outside air to enter the building.

4.7.3.2 Solution

Place insulated metal panels in these openings that will stop the infiltration of outside air from entering the building.

4.7.3.3 Savings

It is estimated that closing these openings will reduce the infiltration by 200 CFM. This will provide an energy savings of 9.6 MWHth/yr. Savings are calculated as:

Q= 1.08 X 200 CFM X (64.4 – 39) °F X 6000 hrs/yr/ 3413 MWH/Btuh = 9.6 MWHth

Energy cost savings = 9.6 MWHth X $65/MWHth = $627/yr (480 €)

4.7.3.4 Investment

The cost to install metal panels to fill these openings is $1,000 (769 €).

4.7.3.5 Payback Calculation

The resulting payback is 1.6 yrs.

4.7.4 BE #19: Add Wall Insulation—Building 4171

4.7.4.1 Existing Conditions

This warehouse building has no insulation in its 25,000 sq ft of wall area. The existing wall is metal siding on the outside with a particle board in the inside. The estimated insulating (U) value of the wall assembly is 0.50 Btu/sq ft/°F.

4.7.4.2 Solution

Provide an insulated wall panel on the outside of the building that is composed of an 1 in. of foam covered by aluminum. The resulting new U-value is 0.09 Btu/SF/°F.

4.7.4.3 Savings

The addition of insulation to the warehouse walls will reduce the annual heating use by:

Q = (0.5 – 0.09) Btu/sq ft/ °F X 25,350 sq ft X (64.4 – 39) °F X 6000 hrs/yr / 3413000 Btu/MWH = 464 MWHth/yr

Cost Savings = (464) MWHth X $65/MWH = $30,165/yr (23,200 €)

4.7.4.4 Investment

The estimated cost of installing this new metal panel is approximately $5.00/sq ft of wall area for a total cost of $127,000 (97,700 €).

4.7.4.5 Payback Calculation

The resulting payback is 4.2 yrs.

Table 10. Pirmasens building envelope (BE) ECM summary.

ECM	ECM Description	Electrical Savings MWh/yr	$K/yr	Thermal Savings MWh/yr	$K/yr	Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
BE16	Install Drop Ceiling in Certain Spaces, Building 4000			22	1.4		1.4	32.7	23.4
BE17	Close Opening Above Crane Using Brushes and Rubber Strips, Building 4000			19	1.2		1.2	1.6	1.3
BE18	Close Openings in Carpenter Storage Room, Building 4000			10	0.6		0.6	1.0	1.6
BE19	Add Wall Insulation, Building 4171			464	30.2		30.2	127.0	4.2
Total	Pirmasens Building Envelope ECMs	0	0	514	33	0	33	162	4.9

4.8 Pirmasens CEP

4.8.1 CEP #1: Turn Off District Heating to Buildings In Summer

4.8.1.1 Existing Conditions

The use of district heating in summertime is significant, although there is no real need for heat, unless special circumstances occur (like the cold weather when the energy assessment team visited Kaiserslautern and Pirmasens). During summer periods heat is only needed for heating of tap water. In most cases this is provided by use of electric water heaters. Even so, data sheets show that KAD used 3663 MBTUs of heat in the period June–September during FY 2005, or 1,073 MWh.

4.8.1.2 Solution

Make sure that tap water can be heated by electricity at all facilities. Make necessary investments to ensure that. Shut down all district heating use, close all distribution systems so that no heat is used and is circulating just to create losses.

4.8.1.3 Savings

At an average price of 65 /MWh the summer heating costs were $70,000 in the summer of FY 2005. Looking at the data sheet it looks like the summer price is 37.3 €/MWh in the summer, which is approximately $47/MWh. The value of the summer saving should be in the area of 95 percent net savings if electric water heaters are used and totally avoiding circulating heat losses. The calculated savings are:

Savings = 1073 MWhth * 0.95 = 1,019 MWhth

Savings = 1019MWhth * $47/MWh = $47,909 /yr (36,800 €/yr) in normal years.

4.8.1.4 Investment

Provided information indicates that most buildings already have electric water heaters for summer use. Therefore, an additional investment in the area of $20,000 (15,000 €) should be sufficient to achieve the savings.

4.8.1.5 Payback Calculation

The calculated payback will occur within 5 months.

4.8.1.6 Comments

From the data sheets on consumption figures it can be seen that the potential for savings from not using district heating in the summer are much bigger at other places, e.g., Landstuhl Hospital. It is recommended that this issue also be raised at U.S. Army facilities other than KAD.

Table 11. Pirmasens central energy plant (CEP) ECM summary.

ECM	ECM Description	Electrical Savings MWh/yr	$K/yr	Thermal Savings MWh/yr	$K/yr	Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
CEP1	Turn Off District Heating To Buildings In Summer			1019	47.9		47.9	20.0	0.4

4.9 Pirmasens Electrical (EL)

4.9.1 EL #2: Switch off Computers When Not In Use—Building 4000

4.9.1.1 Existing Conditions

All computers in the area are on always as IT support suggests to facilitate software updates and back-up runs. Screens are switched off for the night in offices, but in the maintenance areas, the screens are often left on.

In Building 4000 in Pirmasens there are about 40 PCs with flat screen monitors. In other buildings there are obviously some more computers, but these have not been included in the calculation.

4.9.1.2 Solution

Activate power-save features or switch computers off when not in use. The power saving settings will allow to switch off screen or hibernate the hard disk.

Updates and backups can be programmed to take place when the computer is switched on or during the lunch-break.

4.9.1.3 Savings

The saving has been calculated assuming that a computer with 17- or 19-in. monitor is using 150W when the screen is on and that a PC in stand-by mode in night-time with flat screen turned off is using 50W. The weekly power-on time for the computers will be reduced from 168 hrs to 50 hrs. The calculated savings are:

Savings = 40 x (168 – 50) hrs/week x 52 weeks/yr x 100W = 24,544kWh/yr

Savings = 24,544kWh/yr x 1KW/1,000W x $80 / MWh = $1,964 / yr (1,510 €/yr)

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.9.1.4 Investment

No investment, most computers already have the possibility for power saving. New advice and instructions from IT support are needed.

4.9.1.5 Payback Calculation

There is zero payback time.

Table 12. Pirmasens electrical ECM.

ECM	ECM Description	Electrical Savings MWh/yr	$K/yr	Thermal Savings MWh/yr	$K/yr	Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
EL2	Switch off Computers When Not In Use Building 4000	24.5	2.0				2.0	0	0.0

4.10 Pirmasens HVAC (HV)

4.10.1 HV #23: Improve HVAC System Controls—Building 4000

4.10.1.1 Existing Conditions

According to Mr. Hans Greb, and also verified by talking to Mr. Weis at the Common Systems section, there are some serious problems with the HVAC system in Building 4000. The building has been in operation since 1990. Insufficient heating and cooling have been experienced since that time. During the team's initial tour through the building, it was noted that some areas were very hot and other areas cold. The working hours are daytime 5 days/week.

AHUs work with increasing return air volume as it gets colder. Many AHUs have both heating and cooling coils. The AHUs themselves seem to be in good condition, but the controls for the supply air temperatures, room temperatures, regulating valves for heating and cooling as well as circulation pumps for heating and cooling are not coordinated. This results in systems fighting each other and consequent waste of energy.

Setpoints for space temperature varying from 20–50 °C. Large air curtain units do not stop when the big doors have been closed. (The switch at the top of the door has a mechanical problems.) Consequently, temperatures can rise to +35 °C in the main working hall sometimes. The greatest problem, however, is that each circulating pump (of at least 30) for every single secondary heating pipe or cooling pipe has its own timer that controls when the pumps switches on and off. This means that when the AHU in the Common Systems section calls for cooling (when it is too hot in that area), it is not certain that the cooling pump even is running. In fact, it is likely not running since all timers have different settings and may conflict with each other. Many mornings occupants are very cold because the AHU was on all night at maximum cooling.

4.10.1.2 Solution

Start all over again. Invest in a new, centralized HVAC control system, without having to take away all regulators etc. Use as much as possible of the old things (regulators, regulating valves, pumps, temperature sensors etc.) Remove all timers for the heating and cooling pumps. Allow the heating pumps to run when outdoor temperature is below +15 °C. Allow cooling pumps to run when the outdoor temperature is over +15 °C. Regulate every AHU with respect to exhaust air temperature or space temperature. Use heating and cooling in sequence to prevent simultaneous use of heat and cool.

Run AHUs only during working hours unless they need to be started in some areas for heating purposes, when they should operate with 100 percent return air. Otherwise it is OK with a curve to operate dampers with respect to outdoor temperature. Although it is energy efficient, one should always keep at least 20 percent outdoor air (which should be sufficient with these large AHUs and only 100 people working in the 11,500 m^2 [133,000 sq ft] building.)

4.10.1.3 Savings

Building 4000 (which is 11,498 m^2) uses 3,300 MWh of heat annually, or 287 kWh/m^2/yr. This is a large amount for such a new building and with AHUs running on lots of return air. A normal (target) value, is no more than 200 kWh/m^2/yr, although the building is quite large:

Savings = (287-200) kWh/m^2 /yr x 11,498 m^2 x 1MWh/1000kWh = 1,000 MWhth

Savings = 1,000 MWhth x $65/MWhth = $65,000/yr (50,154 €)

There are also substantial savings to be made from less cooling, with functioning controls.

4.10.1.4 Investment

A smart purchaser with assistance from good expertise can keep this investment below $150,000 (115,000 €). In other cases, it can be as costly as someone wants it to be.

4.10.1.5 Payback Calculation

Payback within 3 yrs is very likely, or 3 yrs when considering heating costs only. These changes will result in better productivity and less costs for making calls to the contractor to come and fix the system. (When a contractor is paid for each repair incident, there is less incentive to perform high-quality, lasting work.) Lower costs for cooling will reduce the payback time significantly.

The manager who makes the contract payments should investigate and question the amount the contractor is paid annually for Building 4000.

4.10.2 HV #24: Install Door Heater—Building 4155

4.10.2.1 Existing Conditions

Building 4155 at Pirmasens is used to ship parts for the Depot and it is occupied two shifts/day, 5 days/week. Parts are gathered and taken to this building and assembled in their shipping containers for placement. The entrance door has many fork trucks that pass through it and thus the door is open approximately 25 percent of the time (Figure 12). When open cold outdoor air enters the building creating cold drafts and making the space uncomfortable.

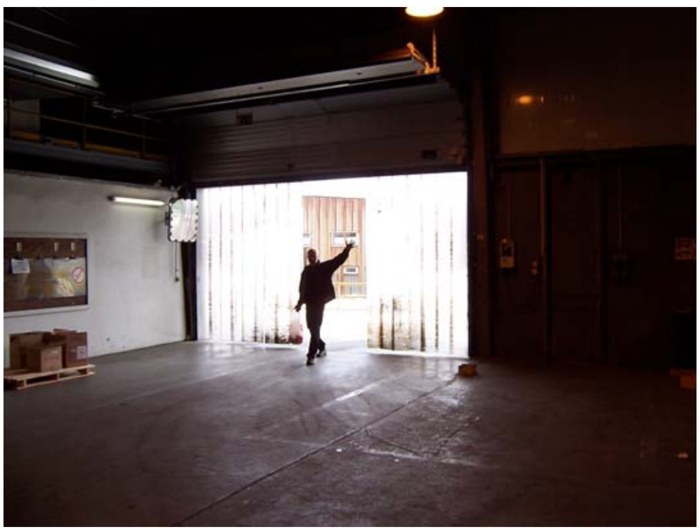


Figure 12. Door in Building 4155.

4.10.2.2 Solution

Place a door heater at this door to reduce the outside air that enters the building. This door heater will also temper the air that does enter the building through the door.

4.10.2.3 Savings

The addition of a door heater on this door will reduce the amount of cold air entering the building. There will be an estimated 3,000 CFM reduction in the infiltration of outside air that would require heating. Savings are calculated as:

> Q= 1.08 X 3,000 CFM X 25% (64.4 – 39) °F X 2080 hrs/yr/ 3413 MWH/Btuh = 13 MWHth
>
> Energy cost savings = 13 MWHth X $65/MWHth = $815/yr (630 €)

4.10.2.4 Investment

The approximate cost for a 12,000 CFM heater for this 10 ft x 12-ft door is $25,000 (19,200 €).

4.10.2.5 Payback Calculation

The resulting payback is 30.6 yrs.

4.10.3 HV #25: Improve H&V System Controls and Air Movement—Building 4171

4.10.3.1 Existing Conditions

Building 4171 in Pirmasens is essentially a warehouse for medicines. The building is occupied weekdays between 6.30 and 19.30. In parts A and B of the building (the oldest parts), heat is provided by oil-fired infrared heaters. These are controlled from a central panel, which has switches Off / Auto / Day / Night. However, the clock identifies “day” or “night” operations (and thus change temperature setpoints) is not working.

Thermostats for the IR-heaters are placed between shelves for automatic trucks. Researchers noted that a thermostat in one of the bays was set at 43 °C, probably changed from the normal 20–22 °C by someone who felt cold one day. According to Karl-Heinz Gaa, who works for the contractor Wisag, the normal setpoint (depending on the products) is 20–22 °C during the day, and +15 °C at night. The question remains whether the products would accept lower temperature at night.

In part C (a newer part), the heat is provided via heated air from *two* direct oil-fired Robatherm AHUs, at 30,000 m^3/h each. These normally run at a minimum outdoor air flow of 20 percent. They can never be stopped, due to safety reasons with the direct firing of oil into the unit. Supply air temperature was +60 °C during the site visit to the building. It is doubtful that existing diffusers can direct the heat down to the floor.

4.10.3.2 Solution

Parts A and B: As at other locations: thermostats should be placed in locked cages, and operated only by the supervisor, who will have the only key. Make necessary investments in programmable timers so the temperature can be reduced to +15 °C at night.

Part C: Replace existing controls of the AHUs with new and modern regulators and controls that can allow the units to stop when nobody works. Control supply air temperature with a maximum of +35 °C and a minimum of +15 °C, depending on measured exhaust air temperature. If a running time of 10 minutes after the burner stops is programmed and if the burner is not allowed to start until the fan is running, the safety issue should be resolved. Allow 15 °C at night as the space temperature (i.e., the exhaust air temperature). It might also be that the burners are too big today, making it necessary to replace existing burners with new, easier to regulate, smaller burners. Perform smoke tests to evaluate the efficiency of air diffusers, which might work better with lower supply air temperature. If they do not, consider changing air diffusers so that the heat can reach the occupancy zone.

4.10.3.3 Savings

<u>Part A and B</u>

At this stage, not enough is known about how the thermostat setpoints have been manipulated and when to make any calculation on the savings. However, upgrading the controls, allowing night-time setback of indoor temperature, will save at least 20 percent of the oil used for the radiant heaters in parts A and B. Unfortunately those specific numbers were unavailable, but a qualified guess, based on an estimated floor space of 9,500 m^2 for parts A and B together, indicates that the 20 percent corresponds to approximately 50 m^3 of oil worth around $26,000/yr. (Data sheets indicate that Building 4171 used 41.3 m^3 of oil in March 2006, which translates to an annual energy use of over 300 m^3/yr. Twenty percent of 300 m^3 is more than what is assumed above.)

Part C

Stopping AHUs 10 hrs/weekday and both Saturday and Sunday will save 105 MWh of electricity (from not running the fan motors) worth $6,300/yr. Changing control method to exhaust air temperature control will prevent overheating and thus unnecessary losses through the roof and doors. Reducing the supply air temperature and allowing lower night and weekend temperatures will save at least as much as for electricity, making the total savings sum up to 105 MWh electricity and 100 MWh of oil (10 m^3) worth totally $13,500/yr (10,400 €/yr).

4.10.3.4 Investment

The total investment for Building 4171 should not exceed $20,000 (15,000 €).

4.10.3.5 Payback Calculation

Total payback time for investments in Building 4171 is less than 6 months.

4.10.4 HV #26: Install Economizers—Building 4111

4.10.4.1 Existing Conditions

At present, the boiler plant generates hot water at a maximum temperature of +110 °C (see HV #32). To accomplish this, the boilers generate 3.3 bar steam at +150 °C. The flue gases from the boilers are normally at +170–180 °C. This is quite high due to the 110 °C hot water distribution temperature. Capacity of boiler is 8,000 kg/h of 8 bar steam.

4.10.4.2 Solution

When the hot water temperature is reduced (as suggested below), install an economizer that can reduce the flue gas temperature to a maximum of 120 °C. This will take more energy out of the used fuel.

4.10.4.3 Savings

Can be calculated as follows:

Flue gas flow: m^3/s.

Reduced flue gas temperature: 50 °C

Fuel costs: $50/MWh

Cp air at 120 °C: 1.015 KJ/kg °C

Density air at 120 °C: 0.9 kg/m^3

Boilers operated Oct 1 to May 31 = 243 days = 5832 hrs/yr

Per Boiler Savings: m^3/s * 1.015 KJ/kg °C * 0.9 kg/m^3 * $50/MWh * 5832 hr/yr * 3,600s/hr x 50 °C x 1MWh/3,600,000KJ = $13,320 * x, i.e., for every m^3/s of flue gases, the annual savings of reducing the flue gas temperature is $13,320 (10,200 €/yr) per boiler, or for all three boilers a savings of $39,960/yr.

4.10.4.4 Investment

The estimated cost to install an economizer in one of these boilers is $30,000, for a total cost of $90,000 (69,000 €).

4.10.4.5 Payback Calculation

The payback on this project is 2.3 yrs:

Payback = $90,000/$39,960/yr = 2.3 yrs

4.10.5 HV #27: Reduce Hot Water Temperatures—Building 4111

4.10.5.1 Existing Conditions

The distribution of hot water from the boiler plant in Building 4111 to the various buildings in Pirmasens follows a curve: At a temperature of –10 °C or colder outdoors, the hot water temperature is 110 °C. At +10 °C or warmer (until the boiler plant is shut down, normally on 31 May) the hot water temperature is 85 °C. A linear curve between these points indicates a supply temperature between +10 and – 10. The spontaneous impression is that this is much too high, at both ends of the curve. This is based on the fact that the ΔT, i.e., difference between supply and return temperatures, normally is only 15–20 °C. At very cold winter days, it can reach 30 °C. With such low ΔT, the energy used to pump water around the system is very high compared to normal district heating systems.

4.10.5.2 Solution

Try to change present heating curve so that the maximum can be lower than 110 °C and also so that the minimum temperature can be *much* lower than 85 °C. (It cannot be necessary to pump around 85 °C water in the system when it is warmer than +10 °C.) A suggested minimum would be +40 °C at +10 °C, and a suggested maximum would be +90 °C at –15 °C, with a linear curve in-between.

It is also suggested that the hot water flow be reduced, although only in cooperation with the people that are in charge of AHUs, radiators etc. This will likely lead to some replacement of inefficient regulating valves and thermostats etc. so that the change does not take the heat out of the system, but lets water just circulate, more or less.

4.10.5.3 Savings

Savings come from reduced losses in the system. When it is warmer than +10 °C, most of the energy used simply keeps the distribution network hot. If the water flow is reduced, energy savings will accrue from less pumping. However, at this stage, it is not possible to estimate the savings.

4.10.5.4 Investment

No investment will be required to change the curve.

4.10.5.5 Payback Calculation

The calculated payback will occur immediately.

4.10.6 HV #28: Install Measurement Equipment—Building 4111

4.10.6.1 Existing Conditions

Building 4111 is the boiler plant, with three boilers that operate on gas or oil. (Last winter, according to Mr. Weber, the plant ran on 60 percent gas and 40 percent oil.) The boiler controls are not optimal. The people working there have no control of the actual boiler efficiency, making it difficult to optimize boiler operation.

4.10.6.2 Solution

Keep track of boiler efficiency (by installing measuring equipment) to always be able to supervise and optimize boiler operation. Alarms should function so that, when efficiency drops, an active personnel or the operator on duty is alerted.

4.10.6.3 Savings

Savings will result from better boiler performance. In FY05, the use of gas and oil at Pirmasens was 55481 MBTU (gas + oil), or 16,250 MWh. That probably also includes Building 4171. (However, assume that all this energy was used to produce district heat at Building 4111.) A 2 percent increase of the efficiency of the boilers would reduce the purchase of gas and oil by 325 MWh, worth $16,500/yr. A 5 percent efficiency increase would save over $40,000/yr (31,000 €/yr).

4.10.6.4 Investment

Installing sensors to measure the critical parameters of the boilers and with an active program at a computer to show actual data as well as historical data should not cost more than $50,000 (38,000 €) for all three boilers together.

4.10.6.5 Payback Calculation

Depending on the present efficiency and how much the efficiency can be improved, payback is estimated to occur in 1–3 yrs.

Table 13. Pirmasens HVAC (HV) summary ECMs.

ECM	ECM Description	Electrical Savings MWh/yr	$K/yr	Thermal Savings MWh/yr	$K/yr	Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
HV27	Improve HVAC System Controls Building 4000		0.0	1000	65.0		65.0	150	2.3
HV28	Install Door Heater, Building 4155			13	0.8		0.8	25.0	29.6
HV29	Improve H&V System Controls and Air Movement In Building 4171, Pirmasens	105	8.4		26		34.4	20	0.6
HV30	Install Economizers, Building 4111, Pirmasens		0.0	799.2	40.0		40.0	90	2.3
HV-31[1]	Reduce Hot Water Temperatures—Building 4111 Pirmasens								immediate
HV32	Install Measurement Equipment, Building 4111	16.5	1.3	812.5	40.6		41.9	50	1.2
Total	Pirmasens HVAC ECMs	122	10	2,625	172	0	182	335	1.8
Note: 1. This no-cost ECM will reduced heat losses in the system with an immediate pay-back									

5 Ansbach, Katterbach Kaserne and Storck Barracks in Illesheim

5.1 Ansbach, Illesheim, and Katterbach ECM Analysis

5.1.1 HV #29: Commissary at Katterbach Building 5805

5.1.1.1 General Site Information

- The building is an old hangar, which has been retrofitted and serves as a commissary in one part of the building and a gym in the other. Gross area 52,330 sq ft (4,868 m^2), Net area 46,050 sq ft (4,283 m^2)
- Retail part has a warehouse with three storages, one of them is cool storage (2 cooling units) and one is cold storage with freezers (5 units).
- The building is connected to district heating system and an electrical grid.
- Operation: 06:00 01:30.
- Open to public between 10:00 and 18:00 5 days a week, between 10:00 and 19:00 1 day a week. Closed on Mondays.

Required temperature in facility: 68 – 72 °F

5.1.1.2 Contact Persons

- Store director: Patrick Hutchins
- Regina Krantz – energy engineer
- Dieter Gerber – electrical engineer
- Helmut Wieder – Technician (UEMCS)

5.1.1.3 Energy Consumption

- Heating energy for year 2005 was 400 MWh
- Electric energy for year 2005 was 1,009 MWh
- The consumption is for a whole building with combined operations.
- Energy bill for year 2005 was 77,911 €.
- Heating: 17,027 €
- Electricity: 60,884 €
- Price of heating energy was 65.76 €/MWh (including fixed prices).
- Price of electricity was 59.46 €/MWh (including fixed prices).

Figure 13. Entrance to the Commissary Building 5805 (Katterbach).

5.1.1.4 Ventilation

The retail shop was equipped with mechanical ventilation system. The system is located in the open attic. Air diffusers are connected using flexible ducts. Air supply is located in the central part of the retails area, and exhaust is from the sides of the retail area. The attic performs as an exhaust chamber. One reason for that is the bearing capacity of the hanging ceiling to hold additional weight.

The warehouse has air handling units providing heating and cooling. Roof has a poor insulation which results in higher heating and cooling loads on the HVAC systems.

Based on the light smell in retail area, it may be suggested that the retail area is under negative pressure against the warehouse which results in the airflow flow from warehouse.

5.1.1.5 Heating

The performance of the radiators in the offices should be checked and avoid the heating by ventilation (if the possibility exists)

There were circulation devices over the retail shop doors, which, according to the manager, did not work properly. This condition could be improved by changing the construction. Also the efficiency should be checked.

5.1.1.6 Existing Conditions and issues

The Commissary (Figure 14) has a number of problematic areas that can be improved:

- The cashier area is cold and drafty.
- The air curtain system is under dimensioned.
- The air recirculation rate (80 percent) is too high.
- Warm air is collected between ceiling and roof.

Figure 14. The Commissary at Katterbach, Building 5805.

5.1.1.7 Solution

- Reduce the air rate by reducing fan speed in the summer time but the outside air rate has to remain constant,
- Integrate the air curtain system in the controls.
- Lengthen the air lock to avoid both doors open at the same time.
- Supply the air lock with exhaust air for heating and pressure maintenance.
- Exhaust air through the insulated duct.
- Install ceiling insulation.

- Install additional fan for exhaust air with the same airflow rate as for supply air fan) and transport this air to the air lock. Install an over-pressure controlled outlet between air lock area and outside.

5.1.1.8 Savings

Old insulation: u = 2 W/m^2K

New insulation: u = 0.5 W/m^2K

Area: 1,100 m^2

Mean outside temperature: 4 °C

Use: 8 h/d ; 6 d/w ; 250 d/yr (= 1,715 h/yr)

Energy costs: $65/MWh

Loss through air curtain: $750/yr

Energy loss with old insulation: 2 W/m^2K * 1,100 m^2 * (20-4) K * 1,715 h/yr = 60.4 MWh/yr

Energy loss with new insulation: 0.5 W/m^2K * 1,100 m^2 * (20-4) K * 1,715 h/yr = 15.1 MWh/yr

Saving: (60.4 – 15.1) MWh/yr * $65/MWh + $750/yr= $3,695/yr

5.1.1.9 Investment

Cost of insulation: $20/$m^2$ * 1,100 m^2 = $22,000

5.1.1.10 Payback Calculation

Payback: $22,000/ $3,695/yr = 5.9 yrs

5.1.2 HV #30: Energy Retrofit in Gym, at Katterbach Building #5805

5.1.2.1 Problem

This building is very hot in summer and the systems are very noisy. There is no control connection between the supply and exhaust systems, and no heat recovery from exhaust air. Systems are allowed to run even when no one is inside.

5.1.2.2 Solutions

Install external shading in front of the windows. Install control connection between supply and exhaust systems. Demand control ventilation with CO_2 sensors. Perform heat recovery in winter time

5.1.2.3 Payback Calculation

Short pay-back period.

5.1.3 HVs #31, #32, #33, #34, #35, #36, #37, #38: Replace Warm Air Heating System with a Hot Water Radiant Panels in Hangars, Katterbach and Ilesheim

5.1.3.1 Existing Conditions

A typical layout for hangars is a total area of 3000 to 5000 $m^{2,}$ of which 1000 m^2 to 1500 m^2 is for aircraft service and the rest is smaller workshop and office spaces. The typical dimensions of the aircraft service area are:

- width and length 30 – 50 m
- depth 15 – 30 m
- height 10 – 15 m.

The heating of the building is water based system; radiators in the workshops and offices, air heaters in the aircraft service areas. The air heaters circulate the air and heat it to a temperature levels of 25–45 °C depending on the heat demand.

The hangars are occupied according to the flight schedules and that means that occupation of the building significantly varies. The most challenging situation for thermal comfort in the hangar is during the winter time when a new aircraft is being moved into the building. The large doors, size of 20x10 m can be open for several minutes and the air of the hangar will be changed several times during the doors being open. The aircraft that will be moved in can weight several tons and has a body with 0 °C temperature.

5.1.3.2 Problems

Warm air heating units and systems installed in the upper zone of hangars do not satisfy thermal comfort requirements in the occupied zone.

Besides, warm air heating is inefficient when air is supplied in high bays with a low speed. When the helicopter is brought in the building in winter time, technicians have to wait a few days before they can start to repair it because the helicopter is too cold, which has an impact on the mission.

The building heating systems are not dimensioned to heat the aircraft during a short period of time. The necessary heat capacity for the warm up of the helicopters has to come from an additional special / separate heating system.

Figure 15. Typical warm air heating units used in hangars.

5.1.3.3 Solution

The circulating air heaters (Figure 15) shall be replaced with radiant heating panels installed at the ceiling level. The panels can use the same hot water system that is used by warm air circulation units.

Building # 5807, Katterbach is used as an example to estimate energy and cost savings. Calculations for other hangars are similar.

Area: 1,930 m²
Energy used for building heating:
  1191 MWh - 50% of the total hangar heating energy.
Energy savings per year: 25%
Energy costs: $60/MWh
Saving: 50% * 1,191MWh * 25% * $60/MWh = $8,940 /yr
Installation of heat radiator panels:
  Panels 90 pieces (3m length) * $525/panel = $47,250
  Piping 100 m * $62.5/m = $6,250

Design $1,250/d * 5d= $6,250

Total cost: $59,750

Payback: $59,750/ $8,940/yr = 6.68 yrs

Table 5 lists calculated cost and savings for hanger circulating heaters based on the fact that the efficiency of the radiant heating is about 25 percent better than that of a corresponding circulating air system.

Table 14. Summary of cost and savings for hanger heating system retrofits.

ECM	Building	Ceiling Area (m^2)	Heating Demand (kW)	Demand per Unit Area (W/m^2)	Unit Size (W)	# Units	Total Cost $*	Energy Savings (MWh/yr)	Savings ($)	Payback (yrs)
HV35	Katterbach 5807	1930	158	79	1750	90	59750	149	8940	6.7
HV36	Katterbach 5801	1550	122	78	1750	71	40000	90	5900	6.7
HV37	Katterbach 5802	1600	125	78	1750	71	40000	100	6000	6.7
HV38	Katterbach 5508	2210	167	76	1750	95	50000	107	6420	7.8
HV39	Katterbach 5806	2845	215	76	1750	123	62000	80	4800	12.9
HV40	Illesheim 6500	3911	288	74	1750	165	79000	269	16140	4.9
HV41	Illesheim 6501	1932	147	76	1750	84	45000	142	8520	5.3
HV42	Illesheim 6502	3860	283	73	1750	162	83000	235	14100	5.9
*Energy cost: $60 /MWh										

5.1.4 HV #39: Flight Simulator, Building # 6658, Illesheim

Figure 16 shows Building # 6658, Illesheim, which houses the flight simulator.

Figure 16. Flight simulator, Building 6658, Illesheim.

5.1.4.1 General Information

Date built: 1983

Gross area: 35,753 sq ft (3,321 m^2)

Net area: 26,715 sq ft (2,482 m^2)

The building consists of three sections, A, B and C.

Section A was not in use.

In section B, there are office spaces, storages, classrooms, one simulator room and a computer room.

Section C is a simulator hall and some offices related to the simulator operation.

The building is connected to district heating system and electrical grid.

Running hours

Black Hawk UH-60

Government 08:00 – 20:00 daily

Contractors: 06:00 – 23:00 daily

Two simulators: AH-64D

Government: 12 hrs / day

Contractors: 05:00-19:00

Indoor air requirements

Required temperature in facility: 15.5 °C – 26.6 °C

Offices 20 – 22 °C, Rh 40 – 60 percent

Computer room and flight simulator 18.3 – 23.3 °C, Rh = 45 – 65 percent

Contact Persons:

Ron Boese, Quality Assurance Engineer

Kenneth Halter, Manager

Regina Krantz, Energy Engineer

Dieter Gerber, Electrical Engineer

Helmut Wieder, Technician (UEMCS)

5.1.4.2 Energy Consumption

Heating energy for year 2005 was 896 MWh (270 kWh/m^2).

Electric energy for year 2005 was 2 316 MWh (697 kWh/m^2).

Energy bill for year 2005 was 196 629 €.

Heating: 58 923 €

Electricity: 137 706 €

Price of heating energy was 65.76 €/MWh (including fixed prices).

Price of electricity was 59.46 €/MWh (including fixed prices).

Heating energy consists of losses through the building envelope, heating of supply air and heating of domestic water (see Figures 17 and 18).

Electrical energy is used mostly for running the flight simulators and maintaining the indoor air conditions.

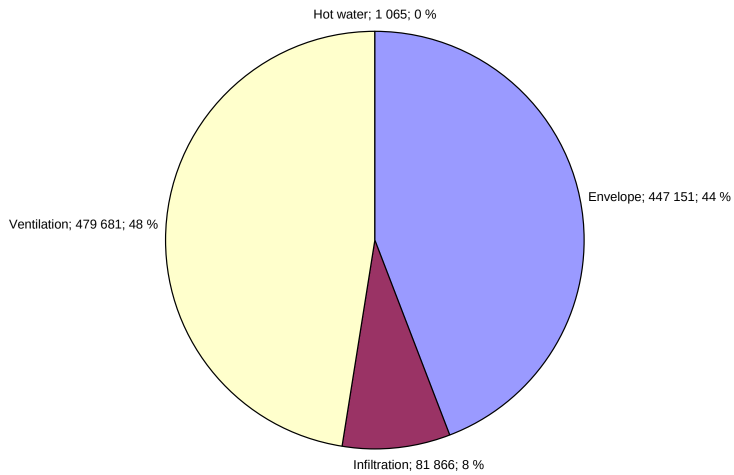


Figure 17. Building 6658 heating energy breakdown.

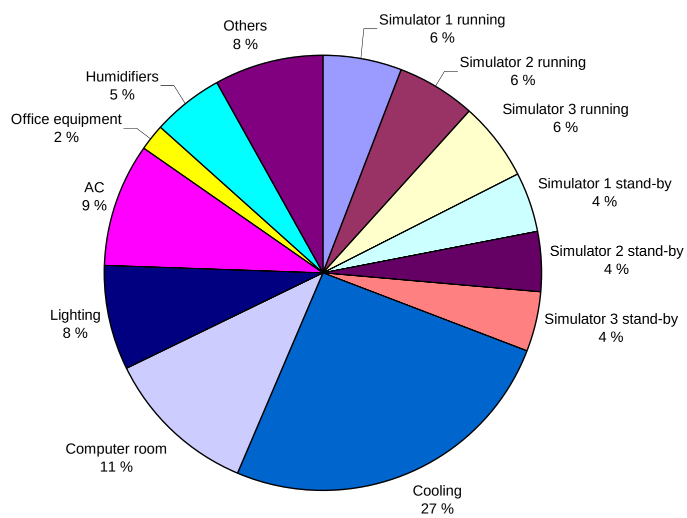


Figure 18. Building 6658 electrical energy breakdown.

5.1.4.3 Systems

5.1.4.4 Building Envelope

Exterior Walls

1. Light concrete block (approximately 20 cm, insulation in between) + metal sheet cover with insulation; estimated U-value 0.30 $W/m^2,K$
2. Steel structures with metal sheet cover with insulation. Insulation approximately 10 cm, estimated U-value 0.45 $W/m^2,K$
3. Roof: Concrete slab with insulation (15 cm), estimated U-value 0.30 $W/m^2,K$

Windows

Thermal panes with light metal frames, U-value is most probably >2.0 $W/m^2,K$. There is a condensation duct in the frames, i.e., direct connection outside, which decreases the total U-value of the window

Window area is relatively small compared with the rest of the building envelope. Some tracks of possible moisture in the windows.

Windows and doors need maintenance, almost all the doors have direct air flow route to outdoor. Seams leak.

Doors

1. Metal doors with insulation
2. Double light metal doors with panes (main entrance)

Based on visual inspection, there were no visual damages in the foundations. Walls all over covered with metal sheets were in acceptable condition, no visual findings from the roof.

5.1.4.5 AC System

The indoor air temperature and humidity are maintained with four AC units.

1. Offices
2. For FS trailer
3. Not in use
4. Computer room and the separate simulator room.

The units are equipped with heating, cooling, humidification and return air function (see Figure 19). AC units are run using constant air volume and 24/7.

Inefficiencies: Inefficient humidification and dehumidification strategies of AC units.

Wastes: AHU of office space is run 24/7.

Figure 19. Flight simulator trailer with attached flexible hoses from HVAC system.

5.1.4.6 Electrical

Electrical supply is connected to transform station. There were two 1000 kVA transformers in use and one 1000 kVA transformer not in use.

5.1.4.7 Indoor Air Quality

All the office rooms on the left side of the lobby were cold and drafty and according to the users very cold in the winter. Additional electric heaters were in use. Also the office room (not originally designed for that purpose) by the trailers were cold. (Extra heaters were in use.) Relative humidity has been relatively high according to the users.

5.1.4.8 Problems

- High energy consumption by HVAC systems.
- Constant volume systems for both high bay areas with simulators at a variable load.
- Mixing losses in the AHU (air treatment).
- Inefficient fans and motors.
- Old chillers.
- Control system is out of order. Inefficient pneumatic controls. Sensors not calibrated No hydraulic adjustment.
- HVAC running time doesn't correspond with simulators use. Air rate cannot be changed with the load. No heat recovery system.

5.1.4.9 Recommendations

Replace pneumatic controls with DDC controls. Airflow control needs installation of frequency converter.

Additional insulation is probably not cost effective. However, air leaks through the windows and doors shall be as a part of the normal maintenance work.

Needs further evaluation of required airflow rate, heating and cooling loads, requirements to air quality, process and comfort related thermal requirements in the various parts of the building should be evaluated. The real cooling need of the building and simulators should be evaluated with logger measurements. Chillers and their operation and running order should be inspected too. After that it is recommended to:

- separate HVAC service areas from each other
- commission HVAC systems to operate in required levels
- install frequency converters and controls for to operate fans
- potential for speed controlled pumps.

Replace old equipment with the new, since it is way over its operational lifetime.

Based on the above analysis, this building has significant potential for energy savings and improvement in thermal comfort and indoor air quality. However, based on importance of the mission and complexity of process and building systems, a Level II energy audit is required to analyze specific energy conservation measures and resulting savings. This assessment should be performed in cooperation with consultants and the users and maintenance personnel of the facility.

5.1.5 LI #19: Improve Lighting Efficiency in Hangars

5.1.5.1 Issue

Inefficient lighting due to dark floors and inefficient lighting systems resulting in increased electrical energy consumption.

5.1.5.2 Solution

Consider holistic lighting solution which includes reducing the number of lamps, changing the lamps to more energy effective and improve the illumination by treating the floor surfaces to be more reflective as in the Hangar 2, Katterbach.

Table 15. Ansbach, Illesheim, and Katterbach recommended ECMs.

ECM	ECM Description	Electrical Savings MWh/yr	$K/yr	Thermal Savings MWh/yr	$K/yr	Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
HV33[1]	Heating system improvement in Commissary at Katterbach Building 5805		-	45.3	3.700		3.700	22.0	5.9
HV34	Energy Retrofit in Gym-Building 5805								
HV35	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5801			149	8.940		8.940	59.75	6.7
HV36	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5802			90	5.900		5.900	40.00	6.7
HV37	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5508	-		100	6.000		6.000	40.00	6.7
HV38	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5807		-	107	6.420		6.420	50.00	7.8
HV39	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5806	-	-	80	4.800		4.800	62.00	12.9
HV40	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6500	-	-	269	16.140	-	16.140	79.00	4.9
HV41	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6501	-	-	142	8.520	-	8.520	45.00	5.3
HV42	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6502	-	-	235	14.100	-	14.100	83.00	5.9
HV43[2]	Complex Energy Retrofit at Flight Simulator Building 6658, Illesheim								
LI19[3]	Improve Lighting Efficiency in Hangars								
Total	Ansbach area	-	-	1117.3	74.5	-	74.5	480.75	6.45

Note: 1.Compex implementation of this ECM will reduce energy consumption and will result in improved thermal comfort, Short payback period.

2. This building has a significant potential for energy savings and improvement in thermal comfort and indoor air quality. Requires a Level II energy audit.

3. This ECM provides a holistic approach to lighting solution which includes reducing the number of lamps, changing the lamps to more energy effective and improve the illumination by treating the floor surfaces to be more reflective as in the Hangar 2, Katterbach. Pay-back in 2-3 yrs

6 Annex 36 Energy Concept Adviser (ECA) Application at Two U.S. Schools in Wiesbaden, Germany

Prepared by Heike Erhorn-Kluttig, Hans Erhorn, Anna Staudt (Fraunhofer-IBP)

Energy Concept Adviser (ECA) developed under the International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems (ECBCS) Annex 36 was used to assess potentially energy savings at two schools located at the U.S. Army Garrison Wiesbaden. This study was conducted by Heike Ernhorn-Kluttig, Hans Erhorn and Anna Staudt (Fraunhofer Institute of Building Physics, Stuttgart) in August 2006.

6.1 Summary

The ECA tool should be tested on a U.S. school in Germany. The U.S. Army Corps of Engineers, through their contacts in Germany, chose two schools, the Elementary and the Middle School Hainerberg in Wiesbaden Hainerberg. A building visit took place on 18 August 2006. Both schools were visited in an common inspection activity by one representative from the Engineer Corps of the U.S. installation (Mr. Utermöhlen), partly assisted by the facility manager, and by three researchers from Fraunhofer-IBP for altogether about 5 hrs. During this visit the team made a thorough analysis of the existing state of the building including the building components (non-destructive analysis, only), the service systems and investigations at the users (school principals and caretakers). Before the visit electronic architectural drawings were sent and during the visit additional plans were handed. However it has to be mentioned that the drawings were only floor plans of differing quality, no sections were available. The following report summarizes the found existing state of the two buildings and the input into the tool and the results of the calculation made with the ECA tool. All areas, volumes, and the input of both schools were calculated in 10 hrs, and the report was constructed in 2 hrs. During the visit it became clear that the chosen examples were not the most suitable for the ECA test as the schools were both in very good shape and some retrofit measures had already been realized.

For the use of the ECA, the parts of the buildings that cannot be included are: the sports hall, the assembly hall (used as canteen, too), and the school kitchen. Table 16 and Figures 20 and 21 describe and show the school buildings.

Table 16. General Data

	Elementary School	Middle School
Address of project	Hainerberg Elementary School Building 07778 Texasstraße 65189 Wiesbaden	Hainerberg Middle School Building 07778 Texasstraße 65189 Wiesbaden
Year of construction	1982	1954
Year of renovation		- probably 1982 (now same windows as Elementary School)
Renovations		- roof insulation - connection to district heating system (original plan: coal cellar)
Total floor area	12264 m²	6862 m²
Number of pupils	~ 810 pupils	~ 420 pupils
Number of class rooms	53	34
Typical classroom	115 m²	94,5 m²

Figure 20. Hainerberg Elementary School.

Figure 21. Wiesbaden American Middle School.

6.2 Site

Wiesbaden, which is located near the center of the Hainerberg area, is surrounded by U.S. military barracks and other military buildings, and has the following geographic characteristics:

- Latitude: 50.3
- Longitude: 8,2
- Altitude: 120 m above sea level
- Test reference year: TRY Frankfurt.

6.3 Typology/Age

The two blocks now used as the Middle School were built in 1954. In 1982, the other school part (used as Elementary School) was added with a facade view similar to that of other older school buildings. A small part of the Elementary School is used as kindergarten, which also has an additional separate building.

6.4 Building Construction

The two buildings are attached to each other. Figures 22–24 show general and detailed floor plans for the Elementary School and Middle Schools.

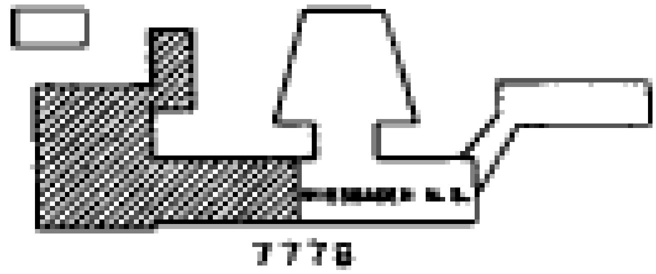


Figure 22. General floor plan layout of the Elementary (left) and Middle (right) Schools.

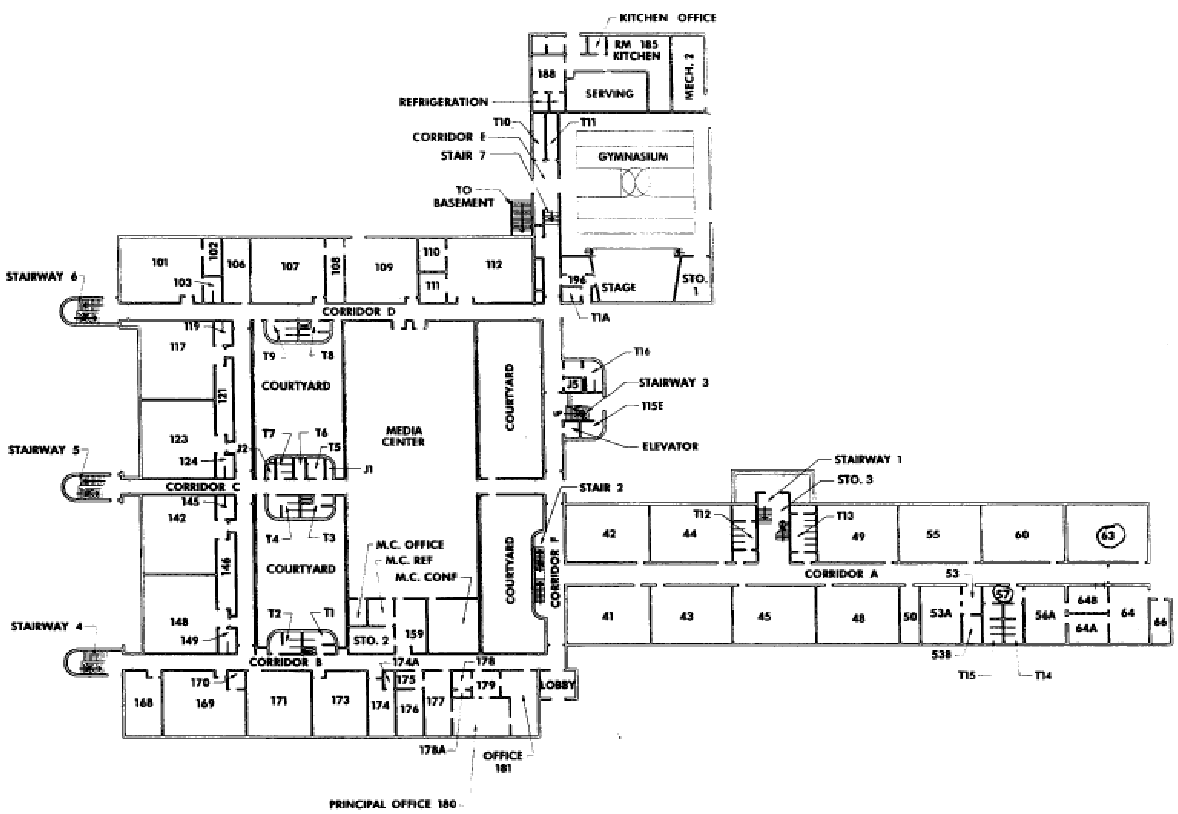


Figure 23. Elementary school floor plan, Building 7778, first floor.

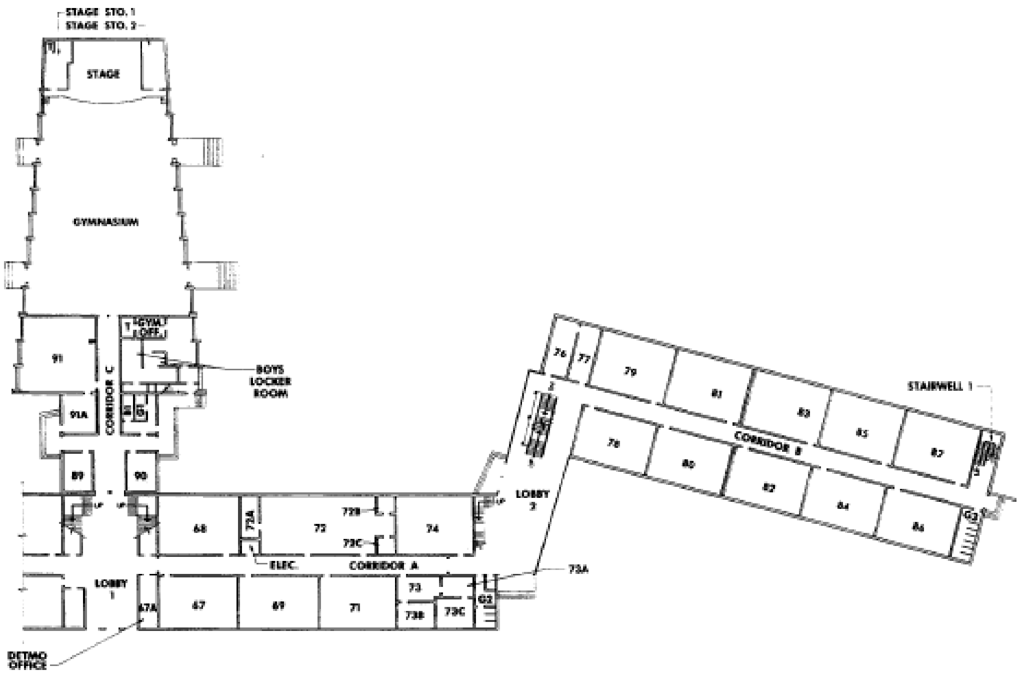


Figure 24. Middle school floor plan, Building 7778, first floor.

6.4.1 Elementary School

The exterior wall (Figure 25) consists of reinforced concrete panels between reinforced concrete columns. The concrete panels are covered from the outside with about 4 cm of mineral wool, 2 cm ventilated air gap and either additional 12 cm concrete panels, or concrete panels with glued clinker (2 cm) between the windows.

Figure 25. Elementary school exterior wall.

The red aluminum-framed windows (Figure 26) are double glazed, filled with air. Every second window is operable. The frames do not include a thermal barrier. All windows are covered with a foil (profilon) fixed on the internal side that prevents splitting and works as a shade. The foil was recently added and seems to be a requirement for all U.S. military school buildings.

Figure 26. Double glazed red aluminum-framed windows.

The classrooms, traffic areas, and other room types have suspended acoustical ceilings that include the lighting systems (Figure 27). The floor construction contains partly cable ducts. The unobstructed room height is 2.75 m. A special case for the classroom situation is on the second floor where above the library (media centre) area, four sets of four classrooms are grouped around a common room in the centre area.

Figure 27. Typical classrooms with suspended acoustical ceilings that include lighting systems.

The Elementary school has a flat roof (Figure 28) that was renovated in 2002. It consists of steel, insulation, sealing, and grit as cover. The building has a small partial basement. In most areas, it has a base slab. Neither the cellar ceiling nor the base slab is insulated, both are constructed with reinforced concrete.

Figure 28. Elementary School roof.

6.4.2 Middle School

The Middle School is as explained the older building, the newer Elementary School was adapted in its façade outlook to the Middle School. The exterior walls are also constructed with reinforced concrete columns. The fields between the columns consist of concrete panels with fixed clinker without insulation and air gap (Figure 29).

Figure 29. Middle School façade.

The windows have been exchanged in an earlier retrofit and are similar to those of the Elementary School. The aluminum-framed windows in red have a double pane glazing, filled with air. The frames are again without thermal barrier. All windows are covered with a foil (profilon) that prevents splitting and additionally works as a shade. The foil was added not so long ago and seems to be a requirement for all U.S. military school buildings. Here the shading system is on the external side. The classrooms and the traffic areas show suspended acoustic ceilings (Figure 30).

Figure 30. Suspended acoustic ceilings in classroom and traffic areas.

The second floor has an inclined roof (Figure 31). Originally the corridor in the middle of two classroom wings had a skylight that provided additional daylight to the classrooms. For fire safety, these skylights were removed from the classrooms and the corridor, which were then painted and glazed white, and insulation was added to the exterior part of the roof, including the formerly exterior glazing. The fire safety (F90) was achieved by adding gypsum boards to the interior glazing and the corridor ceiling.

Figure 31. Second floor inclined roof.

About half of the building has a basement. The basement rooms are on the one side used as additional classrooms if necessary and on the other side as storage rooms. The storage rooms have a lower ceiling height. There is no insulation on the cellar ceiling nor on the base slab, both are made of concrete. Under the other part of the building, there is a crawl space.

6.5 Heating/Ventilation/Cooling and Lighting System

6.5.1 Heating System

Both buildings use district heating as generation system. The supply heating water is provided via a heat exchanger (Figure 32).

Figure 32. Heat exchanger.

The distribution system is either in the crawl cellar of the Middle School (Figure 33) or above the suspended ceilings in the Elementary School. The pipes are insulated.

Figure 33. Middle School crawl cellar.

The Elementary School uses convectors (e.g., library, kindergarten) or radiators (classrooms) as emission system, the Middle School radiators. It has to be mentioned that in part of the Elementary School, specifically the kindergarten, cupboards are placed in front of the convectors, which prevents effective and quick heating of the rooms.

Figure 34. Elementary School cupboards placed in front of the convectors.

6.5.2 Domestic Hot Water System

The Elementary school offers hot water in all classrooms. Partly this is realized centrally, partly decentralized by small electric hot water boilers. The lavatories in both schools offer mostly central hot water. The DHW storage heated by the district heating contains 145 L for the Elementary School.

6.5.3 Ventilation

Ventilation is mostly realized naturally by operable windows. For some special classrooms like the 4X4 grouped classrooms in the Elementary School and chemical and cookery classes in the Middle School, additional mechanically exhaust ventilation is provided.

The canteen in the multi-purpose room of the Elementary School features an air-heating system. The fresh air rate can be manually adjusted. The heat register is directly connected to the district heating system. There is no heat recovery. The ventilation system is from the time of the construction of the building. In the lavatories, exhaust ventilation systems have been added within the windows. In some server rooms, an exhaust ventilation system has been installed.

6.5.4 Cooling

Very few special rooms have a cooling system with a split unit of 12.5 kW.

6.5.5 Lighting

All classrooms have daylighting access from one of the exterior walls. Most classrooms have a renewed artificial lighting system with electronic ballasts and fluorescent tubes with either 18 W per tube or 36 W per tube direct lighting. A typical classroom has eight luminaires with four 36W tubes for an area of 115 m^2 (Figure 35).

Figure 35. Typical classroom luminaires.

The luminaires in the classrooms are manually controlled in two segments (façade near, middle, and corridor near). Additionally the middle and corridor near area can be reduced by 50 percent of the tubes. Alternatively, two other control strategies mainly in the Middle School have been detected:

- All luminaires can be reduced by 50 percent of the tubes. No distinction between façade near area and corridor near area
- Some classrooms have a control that can turn off parts of the luminaires, but unfortunately divided into front and back of the classrooms, not façade near and corridor near.

A typical corridor (length = 119 m) installation consists of 27 luminaires with two 36W tubes each (figure 36). The corridors are additionally centrally controlled that means the lighting can be turned off (except the security light). This is done at night and during weekends.

Figure 36. Typical corridor luminaire installation.

Some rooms in the Middle School still show the original lighting system with suspended luminaires with inefficient reflectors and only turn on and off control (Figure 37). The ballasts are exchanged as they fail (not on a regular schedule).

Figure 37. Original suspended luminaire lighting system.

6.6 Problems/Damages

During the building inspection the following problems were found:

- The windows include only one sealing lip. This leads to water intrusion at the west façade during rain.
- Convectors behind cupboards. As mentioned, in some classrooms of the elementary school cupboards are placed right in front of the heating emission system. Obviously this causes slower heating of the rooms in the morning and more heating losses through the walls.

- Partly inefficient reflectors for lighting. The few remaining old luminaires in the middle school should be replaced by more efficient luminaires with better reflectors.
- Partly inefficient lighting controls (see lighting description).
- In some technical rooms the domestic hot water pipes are installed without insulation throughout the room. This leads to unnecessary high distribution losses.
- The ventilation system of the assembly room of the elementary school has no heat recovery. The whole ventilation system is 40 yrs old, and as would be expected, is very ineffective. For instance, the fans will have a much higher installed power than necessary.
- The glazing is covered with the protective foil. This foil reduces the solar gains and the daylight availability. If the foil is not necessary as sight protection from the outside, but purely as security against glass breakage, it is advised to change to a more transparent foil.
- The computers in the central computer rooms were not turned off, even though the building visit was made at the end of the summer break. It has to be expected that the computers are also not turned off at the end of a school day. Standby losses are considerable as electrical energy has a high primary factor and high costs.
- Ventilation system of the kitchen without heat recovery, therefore unnecessary high ventilation losses.
- The heating system has no weekend or holiday setback mode.
- The insulation of the heat delivery system in the crawl space and at the transfer station of the district heating system is not "state of the art" and is partly damaged, resulting in necessarily higher delivery losses.
- There is no metering system for the schools for heat or electricity. The whole building complex Hainerberg seems to have only one metering system, which makes it difficult to measure and compare energy consumption of specific buildings.

6.7 Evaluation of the Schools within the Energy Concept Adviser

The Energy Concept Adviser can evaluate different configurations of building components, including various heating, ventilation, and lighting systems. For each school building component, the most similar component in ECA was selected to best approximate actual building conditions (Tables 17 and 18).

Table 17. ECA Elementary School configuration.

Component	Description	Characteristic Value
Exterior wall	Concrete sandwich construction	U=0,8 W/m²K
Flat roof	Concrete, insulation, bituminous sealing	U=0,9 W/m²K
Base slab	Concrete, screed floor	U=3,3 W/m²K
Windows	Double glazed, metal frame, not decoupled, no sealing	U=4,0 W/m²K g=78 %
Solar shading system	Internal shading system	
Heating and ventilation system	District heating, 90/70 °c, natural ventilation, night set-back	
Lighting system	Fluorescent tubes, manual switch	

Table 18. ECA Middle School configuration.

Component	Description	Characteristic Value
Exterior wall	Concrete brick construction	U=1,4 W/m²K
Pitched roof	Insulation between the rafters, tiles	U=0,6 W/m²K
Base slab	Concrete, screed floor	U=3,3 W/m²K
Windows	Double glazed, metal frame, not decoupled, no sealing	U=4,0 W/m²K g=78 %
Solar shading system	External shading system	
Heating and ventilation system	District heating, 90/70 °c, natural ventilation, night set-back	
Lighting system	Fluorescent tubes, manual switch	

A summary of the used general cost values is given in the following:

- Inflation rate: 2 %
- Interest rate: 3 %
- Energy prices:
  - district heating: fixed price: 410 €/yr, consumption based price: 3,8 €ct/kWh
  - electricity: fixed price: 95 €/yr, consumption based price: 11 €ct/kWh.

The energy prices were requested from the facility manager of the site. They have not been received by the time of the report and might change slightly the results. For now the default values from the ECA tool were taken.

6.8 Energy Consumption of the Existing State

The two buildings are not individually metered; therefore actual energy consumption of the two buildings is unknown. Table 19 lists calculated energy demand.

Table 19. Calculated energy demand of the existing state according to the Energy Concept Adviser.

Characteristic Value	Unit	Elementary School	Middle School
Floor area	m^2	12264	6862
Final heating energy demand	kWh/m^2a	359.0	347.1
Final electricity energy demand	kWh/m^2a	6.4	6,0
Total primary energy demand	kWh/m^2a	485.9	469.6
CO_2 emissions	kg/m^2	63.5	61.2

Benchmark values (Table 20) were taken from a national study prepared by Fraunhofer Institute of Building Physics, which gathered energy consumption from schools and university buildings. Energy consumption for more than 300 different schools were collected and statistically analyzed.

Table 20. Benchmarks for German Schools as used in the Energy Concept Adviser.

Benchmark Value	Unit	Low	Average	High
Heating energy consumption	kWh/m^2a	88	211	374
Electrical energy consumption	kWh/m^2a	6	20	46

Though consumptions that form the basis of the benchmarks and demands as calculated with the ECA tool are not totally the same (influence of users and weather), the comparison of the data leads to the following assessment:

- Both U.S. schools situated in Hainerberg, Germany have heating energy demands that are much higher than the average of the study and therefore an energy efficiency retrofit is recommended.
- In the case of the electrical energy the benchmark consumptions include more than only the lighting and the auxiliary electrical heating energy as in the calculated ECA electricity demand. However it can be said that the electricity demand of the two buildings is not extreme. Anyway, a better lighting control can lead to better results.

6.9 Retrofit Concepts According to the ECA

For both buildings five different retrofit concepts have been assessed with the Energy Concept Adviser. It has to be mentioned that the ECA offers a list of possible measures for each building and system component that can be combined to retrofit concepts in a second step. It is not a planning tool, but the first rough analysis of suitable retrofit measures for educational buildings. The concepts summarized in this chapter are general. However, the recommendations for retrofit listed in section 6.10 are more building specific and are derived from the experience of the building inspectors (Tables 21 and 22).

Table 21. Elementary School retrofit concepts.

Retrofit Measures	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Heating system: reduction of system temperature to 55/45 °C, new transfer station, zone control, replacement of the DHW storage and the circulation pump					X
Windows: new plastic framed windows, double pane with low-e coating and gas filling, U=1,1 W/m²K	X			X	X
Flat roof: 6 cm of insulation below the ceiling				X	X
Lighting control: occupancy sensors		X		X	X
Exterior wall: 12 cm insulation + plaster on the exterior side				X	X
Solar shading: replace internal shading with external shading system	X		X	X	X

Table 22. Estimated results from implementing Elementary School retrofit concepts.

Results	Unit	Existing Building	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Final heating energy demand	kWh/m²a	359.0	289.6	360.2	359.0	239.1	108.4
Final electricity energy demand	kWh/m²a	6.4	6.4	5.0	6.5	5.0	5.0
Total primary energy demand	kWh/m²a	485.9	395.0	483.1	485.9	325.7	154.1
CO_2 emissions	kg/m²	63.5	52.0	62.9	63.5	42.7	20.7
Investments	€	-	952000	258000	230000	1905000	2763000
Static amortization	a	-	19.1	129.2	∞	28.2	15.5

The calculated results for the five different concepts show (Table 23) that the lighting control based on occupancy sensors (Concept 2 and part of concepts 4 and 5) can probably not be realized in a cost-efficient way. The windows, the flat roof insulation and the insulation on the exterior wall are interesting measures in terms of energy efficiency but not cost-efficient (Concept 4). In combination with a revised heating system with lower temperatures (Concept 5). The measures are getting cost-efficient if the period of analysis is more than 15 yrs. According to the calculation with the ECA these measures should be further analyzed in a future retrofit project.

The calculated investment costs for Concept 5 are 2.8 million Euros, related to the floor area about 225 €/m². The reduction of the heating energy consumption for this concept is 251 kWh/m² or 3073000 kWh/yr.

The results (Table 24) have to be regarded under the aspect that no anyway measures have been used as basis (renovation measures that need to be done without any energy-efficiency reasons and will therefore reduce the costs of more energy-efficient measures). An example for anyway measures might be the untight windows. Additionally the used energy tariffs are quite low as the default values are taken from the energy tariffs of a municipality with lots of buildings and therefore special tariffs.

Table 23. Middle School retrofit concepts.

Retrofit measures	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Cellar ceiling: insulation (6 cm of polystyrene below the ceiling)			X	X	X
Exterior wall: 12 cm insulation + plaster on the exterior side			X	X	X
Heating system: reduction of system temperature to 55/45 °C, new transfer station, zone control, replacement of the DHW storage and the circulation pump				X	X
Windows: new plastic framed windows, double pane with low-e coating and gas filling, U=1,1 W/m²K	X		X	X	X
Lighting control: occupancy sensors		X			X
Shading system: New external shading system	X		X	X	X

Table 24. Estimated results from implementing Middle School retrofit concepts.

Results	Unit	Existing Building	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Final heating energy demand	kWh/m²a	347.1	262.4	348.2	203.0	129.7	131.1
Final electricity energy demand	kWh/m²a	6.0	6.0	4.6	6.0	5.3	4.0
Total primary energy demand	kWh/m²a	469.6	359.0	466.4	283.0	184.4	182.4
CO_2 emissions	kg/m²	61.2	47.2	60.6	37.5	24.8	24.5
Investments	€	–	682000	144000	877000	1358000	1502000
Static amortization	a	–	19.7	133.3	15.5	13.0	14.3

Very similar to the calculations for the Elementary School calculated results for the five different concepts show that the lighting control based on occupancy sensors (Concept 2 and part of Concept 5) can probably not be realized in a cost-efficient way. The windows, the cellar ceiling and the insulation on the exterior wall are interesting measures in terms of energy efficiency and cost-efficiency (Concept 3) with about 15-yr static payback time. In combination with a revised heating system with lower temperatures (Concept 4) the measures are getting more cost-efficient and the static amortization is 13 yrs. According to the calculation with the ECA these measures should be further analyzed in a future retrofit project.

The calculated investment costs for Concept 4 are 1.4 million Euros, related to the floor area about 200 €/m². The reduction of the heating energy consumption for this concept is 217 kWh/m²a or 1491000 kWh/yr.

The results have to be regarded under the aspect that no anyway measures have been used as basis (renovation measures that need to be done without any energy-efficiency reasons and will therefore reduce the costs of more energy-efficient measures). An example for anyway measures might be the untight windows. Additionally the used energy tariffs are quite low as the default values are taken from the energy tariffs of a municipality with lots of buildings and therefore special tariffs.

6.10 Recommendations

The retrofit advice given here can be divided into two different types of measures. The first are the measures that seem to be interesting based on the calculation of the Energy Concept Adviser. The second are the measures that should be realized to improve the problems that were found during the building inspection. Most of these measures cannot be analyzed in detail with the Energy Concept Adviser as they are too building specific. Some of the measures are for building parts that cannot be calculated with the ECA (e.g., the assembly hall, the kitchen and the gym).

6.10.1 Elementary School

- Measures to be evaluated in more detail based on the ECA results: Combination of:
  - new windows, double pane with low e-coating and gas filling (cheapest solution would be plastic frame), U-value ~ 1,1 W/m²K
  - replacement of internal shading with external shading system
  - additional insulation below the flat roof (uppermost ceiling)
  - insulation on the external wall for example with a composite insulation system (insulation + plaster), ~ 12 cm of polystyrene or mineral wool
  - reduction of the heating system temperature to 55/45 °C, new transfer station of the district heating system, evaluation of a zone control
- Measures to be considered to improve the existing situation (problems):
  - add better sealing to the existing windows or exchange windows with a better quality (sealing and U-value)
  - remove cupboards from the heating emission system (radiators/ convectors)
  - improve the efficiency of the ventilation system of the assembly hall
  - improve the efficiency of the ventilation system of the assembly hall (smaller fan motors, add heat recovery)
  - remove the protective foil from the glazing. If the foil realizes a safety measure replace with transparent foil
  - turn off the computers completely when not in use
  - add weekend and holiday setback to the heating system
  - start metering all buildings separately to find out where the biggest energy consumers are and how much energy can be saved with low-cost or no-cost measures
  - add a heat recovery system to the ventilation of the kitchen

6.10.2 Middle School

- Measures to be evaluated in more detail based on the ECA results: Combination of:
    - o new windows double pane with low e-coating and gas-filling (cheapest solution would be plastic frame), U-value ~ 1,1 W/m²K
    - o replacement of internal shading with external shading system
    - o add insulation below the cellar ceiling
    - o insulation on the external wall for example with a composite insulation system (insulation + plaster), ~ 12 cm of polystyrene or mineral wool
    - o reduction of the heating system temperature to 55/45 °C, new transfer station of the district heating system, evaluation of a zone control
- Measures to be considered to improve the existing situation (problems):
    - o add better sealing to the existing windows or exchange the windows with a better quality (sealing and U-value)
    - o replace the partly inefficient lighting reflectors
    - o improve the partly inefficient lighting controls
    - o improve the efficiency of the ventilation system of the assembly hall (smaller fan motors, add heat recovery)
    - o remove the protective foil from the glazing. If the foil realizes a safety measure replace with transparent foil
    - o turn off the computers completely when not in use
    - o add weekend and holiday setback to the heating system
    - o renew/improve the insulation on the heating distribution system in the crawl space and the at the transfer station of the district heating system
    - o start metering all buildings separately to find out where the biggest energy consumers are and how much energy can be saved with low-cost or no-cost measures

Table 25. Summary of all ECMs at Wiesbaden Schools.

ECM	ECM Description	Electrical Savings		Thermal Savings		Total Savings	Investment	Simple Payback
		MWh/yr	$K/yr	MWh/yr	$K/yr	$K/yr	$K	yrs
WS1	Elementary School: Heating System, Windows, Roof, Lighting, Walls, Solar Shading	17.2	2.5	3073	151.8	154.3	3592	23.3
WS2	Middle School: Windows, Roof, Lighting, Walls, Solar Shading	8.6	1.2	1492	73.7	74.9	1765	23.6
Total Schools		25.8	3.7	4565.2	225.5	229.2	5357.3	23.4

7 Summary, Recommendations, and Conclusions

7.1 Summary

An Energy and Process Optimization Assessment (EPOA) study was conducted at selected U.S. Army Installations, which included Keiserslautern Army Depot, Piermasens Army Depot, Katterbach Kaserne, and Storck Barracks in Illesheim. Additionally, a brief assessment visits were made to the U.S. Army Germersheim Army Depot and a warehouse complex Big-O at Defense Distribution Depot Europe (DDDE), and at the U.S. Army Garrison Grafenwoehr to identify potential for energy conservation at those locations. A separate energy assessment analysis of two U.S. Army Garrison Wiesbaden Schools using energy concept adviser (ECA) developed by the IEA ECBCS Programme Annex 36 was performed at later time and its results are included in this report.

Eighty five Energy Conservation Measures (ECMs) addressing Central Energy Plants and distribution systems, Building envelopes, Compressed Air Systems, HVAC, Electrical and Lighting technologies were identified and most of them were quantified economically. If implemented, these ECMs would reduce annual electrical energy consumption by approximately 2412 MWh, thermal heating consumption by 17277 MWh, total operating costs (energy, maintenance and labor) by approximately $1.4 million/yr.

Implementation of these ECMs (Table 26) would cost approximately $9.7 million and would yield an average simple payback of 7.2 yrs. It is recommended that these potential cost savings be aggressively pursued with a program of energy and process optimization and that the 34 low cost/no risk measures be funded internally as soon as possible.

Implementation of 43 moderate cost/low risk ECMs with a higher investment requirements (between $20K and $1 million) will yield annual savings of $989,000, and will require $4.1 million in investments, which will yield a simple payback of 4.2 yrs. (Some of these complex ECMs may require SME support to provide 30 percent design.) These ECMs can be implemented either using central funding or third part financing mechanisms: Energy Savings Performance Contracts (ESPC) or Utility Energy Services Contracts (UESC).

The ECMs for the Wiesbaden Schools show a payback about 23 yrs; it is recommended that thee ECMs be implemented when other retrofit non-energy related projects are planned, or by using ESPC or UESC mechanisms.

This study recommends a separate Level I EPOA assessment of the industrial complex at the Germersheim DDDE and a Level II EPOA assessment at the flight simulator building in Illesheim, since both those locations have a potential to significantly reduce energy use and operating costs, and to improve worker productivity.

The 72 ECMs at Keiserslautern and Pirmasens AD, summarized in Table 27, would reduce electrical consumption by approximately 2,386 MWh, thermal heating consumption by 11,594 MWh, total operating costs (energy, maintenance and labor) by approximately $1.1 million/yr; these ECMs would cost $3.85 million and would yield an average simple payback of 3.5 yrs.

Table 26. Summary of all ECMs.

			Electrical Savings		Thermal Savings		Additional Savings	Total Savings	Investment	Simple Payback
ECM Category	Chapter	# ECMs	MWh/yr	$K/yr	MWh/yr	$K/yr	$K/yr	$K/yr	$K	yrs
Lighting - Kaiserslautern and Pirmasens	4.2	18	367	29.5	0	0	0	29.5	36.8	1.25
Building Envelope – Kaiserslautern	4.3	15			3,702	241	70	311	1,856	6
Compressed Air – Kaiserslautern	4.4	1	203	16				16	2	0.1
Electrical – Kaiserslautern	4.5	1	37	3				3	0	0.0
HVAC – Kaiserslautern	4.6	26	516	41	2745	250	117	408	1346	4.5
Building Envelope - Pirmasens	4.7	4	0	0	514	33		33	162	4.9
District Heating – Pirmasens	4.8	1			1,019	48		48	20	0.4
Electrical Pirmasens	4.9	1	25	2				2	0	0.0
HVAC – Pirmasens	4.10	5	122	10	2,625	172		182	335	1.8
HVAC-Ansbach area:– Katterbach and Illesheim	5.1	11			1117.3	74.5		74.5	481	6.45
Wiesbaden Schools	6	2	25.8	3.7	4565.2	225.5		229.2	5357.1	23.4
Total		*85*	*1296*	*105*	*16288*	*1044*	*187*	*1336*	*9596*	*7.2*

Table 27. Summary of all ECMs at Keiserslautern and Pirmasens AD.

ECM Category	Chapter	# ECMs	Electrical Savings		Thermal Savings		Additional Savings	Total Savings	Investment	Simple Payback
			MWh/yr	$K/yr	MWh/yr	$K/yr	$k/yr	$K/yr	$K	yrs
Lighting - Kaiserslautern and Pirmasens	4.2	18	367	29.5	0	0	0	29.5	36.8	1.25
Building Envelope – Kaiserslautern	4.3	15			3,702	241	70	311	1,856	6
Compressed Air – Kaiserslautern	4.4	1	203	16				16	2	0.1
Electrical – Kaiserslautern	4.5	1	37	3				3	0	0.0
HVAC – Kaiserslautern	4.6	26	1632.4	82.3	3734	275	116.6	475	1433.2	3
Building Envelope – Pirmasens	4.7	4	0	0	514	33		33	162	4.9
District Heating – Pirmasens	4.8	1			1,019	48		48	20	0.4
Electrical Pirmasens	4.9	1	25	2				2	0	0.0
HVAC – Pirmasens	4.10	5	122	10	2,625	172		182	335	1.8
Total		72	2386.4	142.8	11594	494	186.6	1099.5	3845	3.5

The 11 primarily HVAC-related ECMs at Katterbach and Illesheim (described in Chapter 5 and summarized in Table 26) would reduce thermal heating consumption by 1,117,300 MWh, operating costs by approximately $74,5000/yr, cost $481000, and would yield an average simple payback of 6.5 yrs.

Energy conservation concepts developed for the two Wiesbaden Schools (described in Chapter 6 and summarized in Table 26) would reduce electrical consumption by approximately 25.8 Mwh, thermal heating consumption by 4565.2 MWh, and total operating costs by approximately $275,000/yr; these concepts would cost $5.4 million and yield an average simple payback of 23.4 yrs.

7.2 Recommendations

The Level I analysis of multiple complex systems conducted during the EPOA are not intended to be (nor should they be) precise. The quantity and quality of the systems improvement identified suggests that sufficient potential exists. It is recommended that these potential cost savings be aggressively pursued. It is also recommended that the low cost/no risk (so-called "slam dunk") ECMs that can typically be implemented quickly (summarized in Table 28) be funded internally and implemented as soon as possible. All 34 ECMs in this table require an investment of $95K and would yield an average simple payback of about 0.8 yr. Together they have potential to save $118K/yr. All lighting projects under this category can be implemented as a one project.

Table 28. Summary of low-cost/no-risk ECMs.

ECM	ECM Description	Electrical Savings		Thermal Savings		Total Savings $K/yr	Investment $K	Simple Payback yrs
		MWh/yr	$K/yr	MWh/yr	$K/yr			
LI1-LI18	Kaiserslautern and Pirmasens Lighting ECMs	367	29.5	0	0	29.5	36.8	1.25
BE6	Repair door seals, building 2226			9.7	0.63	0.63	2	3.2
BE8	Place insulated panel in unused door areas in building 2371			51.8	3.4	3.4	7.2	2.1
BE9	Repair damaged doors in building 2371			9.7	0.6	0.6	1	1.6
BE14	Repair door seals, building 2370			9.6	0.6	0.6	2	3.2
BE17	Close Opening Above Crane Using Brushes and Rubber Strips, Building 4000			19	1.2	1.2	1.6	1.3
BE18	Close Openings in Carpenter Storage Room, Building 4000			10	0.6	0.6	1	1.6
CA1	Turn Off Air Compressors on Weekends and Nights Building 2224	203	16.2			16.2	1.5	0.1
EL1	Switch off Computers When Not In Use — Bldg 2233	36.8	2.9			2.9	0	0
EL2	Switch off Computers When Not In Use Building 4000	24.5	2			2	0	0
HV4	Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers 1 to 3			36.3	2.4	2.4	12	5.1
HV6	Reduce Excessive Air Use in Welding and Vehicle Exhaust Building 2233	46.4	3.7			3.7	7.5	2
HV13	Place Thermostat Controls Away From Occupants. Improved Control For Air Heaters	105	8.4			8.4	0.2	0.02
HV21	Have Heating Utility Turn off Heat to Buildings when not Warranted							Immediate
HV22	Use Heat from Generator Test for Building Heat, Building 2362			78	5.1	5.1	15	3
HV24	Provide Better Controls Of H&V In Building 2371	365	29.2	600		29.2		0
HV25	Insulate Heating System Components-Building 2371							< 2 yrs
HV26	Provide Temperature Control Of Unit Heaters In Building 2281		0	180	11.7	11.7	7	0.6
Total 35 ECMs		1147.7	91.9	1004.1	26.23	118.13	94.8	0.8

Table 29 summarizes 43 moderate cost/low risk ECMs with a higher investment requirements (between $20K and $1 million). If implemented, these ECMs will together result in annual savings of $989 thousand, will require $4.1 million in investments, and will yield a simple payback of 4.2 yrs. (Some of these complex ECMs may require SME support to provide 30% design.) All projects which propose replacement of unit and other warm air heating systems with hydronic radiant panels are recommended to be packaged and implemented as a one project.

Table 29. Summary of moderate cost/low risk ECMs.

ECM	ECM Description	Electrical Savings		Thermal Savings		Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
		MWh/yr	$K/yr	MWh/yr	$K/yr				
BE1	Use transparent plastic panels behind glass sash, building 2233			2569	167		167	1052	6.3
BE2	a. Reduce solar heat load by use of conventional solar[1] film OR					70	70	280	4
BE3	Add vestibule on west side door of building 2233			137	8.9		8.9	105	11.8
BE5	Provide insulated panels for door openings in building 2222			28.3	1.84		1.84	16.8	9.1
BE7	Add vestibule on west side of building going-up ramp in building 2371			145	9.4		9.4	50.4	5.3
BE10	Insulate north wall bldg 2371			49.8	3.2		3.2	22.5	7
BE11	Use transparent plastic panels behind glass windows building 2281			158	10.3		10.3	64.7	6.3
BE12	Use transparent plastic panels to replace roof skylights building 2281			118	7.7		7.7	70.4	9.2
BE13	Repair and insulate roof building 2281			372	24.2		24.2	149.6	6.2
BE15	Insulate roof in maintenance building #2226			44.8	2.9		2.9	32.8	11.3
BE16	Install Drop Ceiling in Certain Spaces, Building 4000			22	1.4		1.4	32.7	23.4
BE19	Add Wall Insulation, Building 4171			464	30.2		30.2	127	4.2
HV2	Install Exhaust Fans To Ventilate Building 2233					116.64	116.6	65	0.6
HV3	Install Destratification Fans Recover Heat in Upper Strata – Building 2233			700	45.5		45.5	40	0.9
HV5	Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2233,			6.06	98.5		98.5	459.9	4.7
HV7	Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,			95	6.2		6.2	33.95	5.5
HV8	Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,			24	15.6		15.6	97.9	6.3
HV9	Recirculate Exhaust Air Back into Booth During Drying Operations, Building 2225			59	3.8		3.8	20	5.2
HV10	Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2238			185.6	12.06		12.06	98.42	8.2
HV11	Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2239			283.5	18.43		18.43	145.5	7.9
HV14[3]	Increase Ventilation to Reduce Solvent Fumes in Space-Building 2222							40	
HV15	Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop Building 2225			76.5	4.4		4.4	31.75	7.2
HV16[4]	Provide Heaters over Doors on South Side-Building 2226							100	
HV17	Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2226			120	7.8		7.8	54.5	7

ECM	ECM Description	Electrical Savings		Thermal Savings		Additional Savings $K/yr	Total Savings $K/yr	Investment $K	Simple Payback yrs
		MWh/yr	$K/yr	MWh/yr	$K/yr				
HV18	Separate the Building Heating System from the Boiler and Connect the Building to District Heating System at Apprentice Shop, Building # 2364			~25%	~25%				< 5 yrs
HV19	Replace Warm Air Heaters with Hot Water Radiant Panels in Apprentice Shop, Building # 2363			75	4.9		4.9	39.3	8.1
HV20	Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop, Building # 2372			190	11.4		11.4	53.25	4.7
HV23	Provide Door Heater at Door on East Side of Building 2371			36	2.3		2.3	25	10.7
CEP1	Turn Off District Heating To Buildings In Summer			1019	47.9		47.9	20	0.4
HV27	Improve HVAC System Controls Building 4000		0	1000	65		65	150	2.3
HV28	Install Door Heater, Building 4155			13	0.8		0.8	25	29.6
HV29	Improve H&V System Controls and Air Movement In Building 4171, Pirmasens	105	8.4		26		34.4	20	0.6
HV30	Install Economizers, Building 4111, Pirmasens		0	799.2	40		40	90	2.3
HV32	Install Measurement Equipment, Building 4111	16.5	1.3	812.5	40.6		41.9	50	1.2
HV33[1]	Heating system improvement in Commissary at Katterbach Building 5805		–	45.3	3.7		3.7	22	5.9
HV35	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5801			149	8.94		8.94	59.75	6.7
HV36	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5802			90	5.9		5.9	40	6.7
HV37	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5508	–		100	6		6	40	6.7
HV38	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5807		–	107	6.42		6.42	50	7.8
HV39	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5806	–	–	80	4.8		4.8	62	12.9
HV40	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6500	–	–	269	16.14	–	16.14	79	4.9
HV41	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6501	–	–	142	8.52	–	8.52	45	5.3
HV42	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6502	–	–	235	14.1	–	14.1	83	5.9
Total 43 ECMs				10720	793	187	989	4,144	4.2

All moderate cost ECMs can be implemented either using central funding or third party financing mechanism (e.g., Energy Savings Performance Contracts [ESPC] or Utility Energy Services Contracts [UESC]). It is also recommended that the energy projects at Wiesbaden schools (WS-1 and WS-2) be implemented together with other planned retrofit non-energy related projects, or by using ESPC or UESC mechanisms.

Improvements in energy systems providing support to flight simulator building in Illesheim show a significant potential to save energy and reduce operation costs (HV #43). However, this project will require a more detailed (Level II) assessment. A separate Level I EPOA study of the industrial complex at the Germersheim DDDE is recommended, since it may potentially reduce energy use and operating costs significantly, and improve workers productivity.

Energy conservation projects for Continental U.S. (CONUS) based installations shall be based on current U.S. codes and standards. However, implementation of the Army Energy Strategy, EPAct 2005 and Executive Order 13423 require a more aggressive approach. New construction and retrofit projects for European locations follow host countries' energy requirements, which are sometimes more stringent than those for the United States. Appendix D contains (an English version of) some current German standards and guidelines concerning energy conservation. This information may be helpful for projects at both CONUS and outside continental U.S. (OCONUS) locations

7.3 Conclusions

An EPOA is a complex undertaking. Several key elements require significant attention to guarantee success: (1) the involvement of key facility personnel who know what the problems are, where they are, and have thought of many solutions; (2) the facility personnel sense of "ownership" of the ideas, which in turn develops a commitment for implementation; and (3) the EPOA focus on site-specific, critical cost issues, which, if solved, will make the greatest possible economic contribution to facility's bottom-line. Major cost issues are: facility utilization (bottlenecks), maintenance and repair optimization (off spec, scrap, rework), labor (productivity, planning/scheduling), energy (steam, electricity, compressed air), waste (air, water, solid, hazardous), equipment (outdated or state-of-the-art), etc. From a cost perspective, facility capacity, materials, and labor utilization are far more significant than energy and environmental concerns. However, all of these issues must be considered together to achieve DOD's mission of military readiness in the most efficient, cost-effective way. The Energy Assessment Protocol developed by CERL in collaboration with a number of government, institutional, and private sector parties is based on the analysis of the information available from literature, training materials, documented and non-documented practical experiences of contributors, and successful showcase energy assessments conducted by a diverse team of experts at the U.S. Army facilities. The protocol addresses both technical and non-technical, organizational capabilities required to conduct a successful assessment geared to identifying measures that can reduce energy and other operating costs without adversely impacting product quality, safety, morale, or the environment.

Expertise in energy auditing is not an isolated set of skills, methods, or procedures; it requires a combination of skills and procedures from different fields. However, an energy and process audit requires a specific talent for putting together existing ways and procedures to show the overall energy performance of a building and the processes it houses, and how the energy performance of that building can be improved. A well grounded energy and process audit team should have expertise in the fields of heating, ventilating, and air conditioning (HVAC), structural engineering, electrical and automation engineering and, of course, a good understanding of production processes.

Most of the knowledge necessary for energy audit is a part of already existing expertise. Designers, consultants, contractors, and material and equipment suppliers should be familiar with the energy performance of the *specific* field in which they are experts. Structural designers and consultants should be familiar with heat losses through the building shell and what insulation should be added. Heating and ventilation engineers should be familiar with the energy performance of heating, ventilation, compressed air, and heat recovery systems. Designers of electrical systems should know energy performance of different motors, VFD drives and lighting systems. An industrial process and energy audit requires knowledge of process engineers specialized in certain processes.

Critical to any energy and process audit team member is the ability to apply a "holistic" approach to the energy sources and sinks in the audited target (installation, building, system, or their elements), and the ability to "step out-side the box." This ability presumes a thorough understanding of the processes performed in the audited building, and of the needs of the end users. For this reason, the end users themselves are important members of the team. It is critical for management, production, operations and maintenance (O&M) staff, energy managers, and on-site contractors to "buy-in" to the implementation by participating in the process, sharing knowledge and expertise, gathering information, and developing ideas.

Appendix A: Assessments at U.S. Army Germersheim Army Depot, Defense Distribution Depot Europe (DDDE), and U.S. Army Garrison Grafenwoehr

In addition to energy assessment conducted by the team at four Army installations, Keiserslautern, Pirmasens, Ansbach, and Illesheim, on the request from IMCOM European Region energy manager, Mr. David Yacoub, Dr. Alexander Zhivov from ERDC CERL had a brief visits to U.S. Army Germersheim Army Depot and a warehouse complex Big-O at Defense Distribution Depot Europe (DDDE), and to the U.S. Army Garrison Grafenwoehr to assess energy conservation opportunities and to collect "lessons learned" from on-going new construction to be used in similar projects. This appendix summarizes these visits.

U.S. Army Germersheim Army Depot and A Warehouse Complex Big-O at Defense Distribution Depot Europe (DDDE)

This complex has a number of warehouses, some of which were recently renovated, other are considered for retrofits. Some of newly renovated warehouses have daylighting and high efficient fluorescent lights installed (Figure E1)

Figure E1. Warehouse daylighting.

Some warehouses have plastic "speed doors" operating via motion driven sensors (Figure E2). These doors allow personnel while on forklifts, to move from one warehouse to another without taking time to open and close doors and living these doors open only during the minimum required time.

Figure E2. Plastic warehouse "speed doors."

This energy conservation technology is installed so far only in Building 7972 and it is planned to have similar "speed doors" installed throughout DDDE.

Heating systems used in warehouses are either central air or unit air heating systems with a hot water heating coils. They are not efficient, create temperature stratification along the heights and poor performance close to open doors. Energy conservation can be achieved if these systems are replaced with radiant heating systems (Figure E3).

Figure E3. Warehouse radiant heating systems.

Studies conducted by Senergy GmbH analyzed and proposed heating concepts for DDDE considering different heating systems (high and low temperature radian heating) and heat generation options (local gas, oil and biomass based and low temperature hot water district heating).

A separate study may be recommended to improve energy performance of the industrial complex at the U.S. Army Depot with following issues to be addressed: poor lighting systems with a potential to a hybrid lighting, radiant heating system for a high bay, "speed doors" at the high traffic entrances, building envelope insulation, evaporative cooling to reduce indoor air temperature during peak summer loads and to improve soldiers productivity and morale (Figure E4).

Figure E4. U.S. Army Depot warehouses.

U.S. Army Garrison Grafenwoehr

The focus of the assessment was on new tactical equipment maintenance facilities (TEMF) and new and retrofitted barrack buildings. By the time of the visit, the first out of 12 new TEMF facilities was constructed (Figure E5).

Figure E5. Tactical equipment maintenance facility.

New TEMF has four individual bays, equipped with underfloor vehicle exhaust systems and an overhead warm air unit heaters. There is no general ventilation and the intend is to ventilate facilities by opening doors.

Vehicle exhausts have a standard coupling to vehicle exhausts, and will be difficult to use with different types of Army vehicles to be serviced. Changeable nozzles designed for each type of vehicles will be more efficient (Figure E6).

Figure E6. Changeable nozzles designed different vehicle types.

Overhead systems will be easier to use, since they don't take a floor space, e.g., flexible/multifunctional vehicle exhausts on a boom or an exhaust ail (Figure E7).

Figure E7. Overhead vehicle exhaust systems.

Warm air heating systems are inefficient (especially in spaces obstructed by large vehicles). Heating from a hot water district heating system can be done cheaper and more efficient and provide better work environment, if a floor radiant heating system is used for newly constructed TEMF. Radiant floor heating was successfully used at Fort Lewis (Figure E8).

Figure E8. Radiant floor heating at Fort Lewis, WA.

General ventilation is needed (especially during colder times of the year). To preheat supply air a solar wall technology can be used (Figure E9).

Figure E9. Solar wall technology at Fort Drum, NY.

Lighting systems in both TEMF and in sheds shall operate with a sensor to turn them off when the sun is shining (Figure E10).

Figure E10. Example lighting systems with solar sensors.

Hybrid lighting in TEMF (a combination of solar tubes and efficient lights) can be incorporated in the design for new construction (Figure E11).

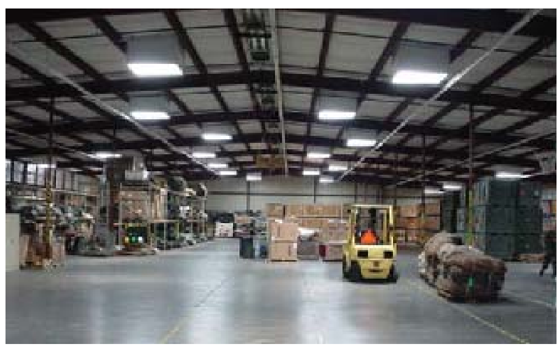


Figure E11. Example hybrid lighting.

One visited hangars was recently insulated using an Energy Savings Performance Contract (ESPC) contract (Figure E12). Door seals were improved. However, central warm air heating system was not changed and is inefficient (warm air is supplied with low velocities in the upper zone and return is located in the lower zone).

Figure E12. Recently insulated hangars.

This defect can be avoided in an energy project in the similar adjacent hangar if/when approved and funded (Figure E13).

Figure E13. Candidate hangar for improved insulation.

New Army barracks construction and retrofits are performed having stringent German and European thermal energy performance guidelines in mind. Table 1 lists requirements for heat flux resistance, and Figure E14 shows German requirements to the building air tightness.

Table E28. Requirements for heat flux resistance.

Line		Components		Heat reflux resistances R in $(m^2 K)/W$
1		Exterior walls; common rooms walls toward basement rooms: passages, open corridors, garages, ground		1,2[a]
2		Walls between external used rooms; flat walls		0,07
3		Stairwell walls	To stairwells with considerably lower indoor temperatures (e.g. indirectly heated stairwell); indoor temperature $\vartheta \leq 10°C$, stairwell shall be at least without frost	0,25
4			To stairwells with indoor temperature $\vartheta > 10°C$ (e.g. administrative buildings, commercials, school buildings, hotels, restaurants and residential building)	0,07
5		Flat walls, ceilings between external workrooms; ceilings underneath rooms between insulated conical roofs and walls in adjacent rooms in case of completed attics	In general	0,35
6			In central heated office buildings	0,17
7		Under closure common rooms without basement	Directly at the ground up to a room depth of 5 m	0,90
8			Above a non-ventilated hollow space adjacent to the ground	
9		Ceilings underneath non-completed attics; ceilings underneath rooms which allows creeping and rooms which are still smaller; ceilings underneath ventilated rooms between conical roofs and walls in adjacent rooms in case of completed attics, insulated conical roofs		
10		Basement ceiling, ceiling toward closed, unheated corridors and others		
11	11.1	ceilings (also roofs) which isolate the common rooms from the ambient air	down, towards garages (also heated), passages (also closable) and creep basement capable to ventilating[b]	1,75
	11.2		upwards, roofs and ceilings underneath terraces etc.	1,2

[a] For buildings with lower indoor temperatures ($12°C \leq \vartheta > 19°C$) : R = 0,55 $(m^2 K)/W$
[b] Increased heat flux resistances because of foot coldness.

- **DIN 4108-2**

The joint permeability coefficient concerning the connection joints of the building components resulting from measurements must be lass than 0,1 m^3/mh (daPa $^{2/3}$).

In case of windows and window doors the requirements acc. to DIN 18055 shall be applied. In case of outer doors the joint permeability coefficient must be a <=2,0 m^3/mh (daPa $^{2/3}$).

- **DIN 4108-7**

If measurements of the air tightness of buildings ore building components are made, the measured air volume flow considering the pressure difference between inside and outside of 50 Pa

- in case of buildings without HVAC systems:
  - depending on the air volume should not exceed $3h^{-1}$
  - depending on the net base-area should not exceed 7,8 $m^3/(m^2 h)$
- in case of buildings with HVAC system (also exhaust air installation):
  - depending on the air volume should not exceed $1,5h^{-1}$
  - depending on the net base-area should not exceed 3,9 $m^3/(m^2 h)$

Figure E14. German requirements to the building air tightness.

Figure E15 shows materials used both in new construction and retrofits. Wall insulation level is U= 0.035 W/m^2*K (brick 12cm+ insulation 14cm + wall blocks 23cm); roof is insulated using the same insulation material.

Figure E15. Insulation materials used in new construction and retrofits.

For new windows U = 0.9 - 1.4 W/m²*K, which replace existing windows with 2.5W/m²*K (Figure E16).

Figure E16. New windows with improved insulating characteristics.

Barracks attic space is used for storage (space utilization and reduced heat losses/gains) (Figure E17).

Figure E17. Barracks attic storage space.

Heating is provided by central low temperature hot water heating system connected to room radiators with an individual thermostat (Figure E18).

Figure E18. Hot water heating system room radiators with individual thermostat.

Hot water pipes for heating and domestic hot water supply are well insulated (Figure E19).

Figure E19. Well insulated hot water pipes.

Entrance doors to individual apartments have keyless entry (Figure E20), which potentially can be linked to controls turning off electrical equipment when apartment is not occupied and setting back radiators' thermostats.

Figure E20. Keyless entry doors.

Closets are ventilated (Figure E21), which reduces odor and mold issues and result in a superior indoor air quality.

Figure E21. Ventilated closet.

Appendix B: Summary of Energy Conservation Measures

Table A1. Summary of energy conservation measures.

ECM	ECM Description	Electrical Savings		Thermal Savings		Additional Savings ($K/yr)	Total Savings ($K/yr)	Investment ($K)	Simple Payback (yrs)	Location
		MWh/yr	$K/yr	MWh/yr	$K/yr					
LI1	Install Energy Efficient LED Exit Lights - Kaiserslautern and Pirmasens	16	1.3				1.3	10.8	8.2	K,P
LI2	Install Occupancy Sensors to Turn off Unnecessary Lighting, All buildings: Restrooms, lunchrooms, etc – Kaiserslautern and Pirmasens	10	0.8				0.8	5	6.2	K,P
LI3	Use Daylight Sensors to Turn off Unnecessary Lighting Building 2233 Maintenance Area	37	3				3	2.5	0.8	K
LI4	Use Daylight Sensors to Turn off Unnecessary Lighting, Building 2233 - Engine repair and other areas on the North side	37	2.96				2.96	2.5	0.9	K
LI5	Install daylight sensors to switch off unnecessary lighting during daylight hours, Building 2281 Warehouse SAK	30	2.4				2.4	2.5	1	K
LI6	Install daylight sensors to switch off unnecessary lighting during daylight hours, Building 4000 Maintenance Area and Bodyshop	37	3				2.95	4.3	1.5	P
LI7	Install daylight sensors to switch off unnecessary lighting during daylight hours, Building 4000 Maintenance-Apprentice Workshop	5.21	0.42				0.42	1.8	4.3	P
LI8	Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2371 Shipping and receiving	6	0.5				0.5	0.5	1.1	K
LI9	Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2370 Security warehouse	85	6.8				6.8	2.5	0.4	
LI10	Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2225 Paint booth	4.2	0.3				0.3	0.4	1.2	P

ECM	ECM Description	Electrical Savings		Thermal Savings		Additional Savings ($K/yr)	Total Savings ($K/yr)	Investment ($K)	Simple Payback (yrs)	Location
		MWh/yr	$K/yr	MWh/yr	$K/yr					
LI11	Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 4000 Paint booths	8.4	0.7				0.7	0.8	1.2	K
LI12	Turn off Halogen Lights When Stacker is not in Use, Building 2281 Stacker lights	5.2	0.4				0.4	0.2	0.5	K
LI13	Replace Mercury Vapor Lamp with More Efficient Type, Building 2371	33	2.6				2.6	0.8	0.3	K
LI14	Replace Mercury Vapor Lamp with More Efficient Type, Building 2370	9	0.7				0.7	0.2	0.3	K
LI15	Replace Mercury Vapor Lamp with More Efficient Type, Building 2213	8	0.7				0.7	0.2	0.3	K
LI16	Replace Mercury Vapor Lamp with More Efficient Type, Building 4171	17	1.4				1.4	0.4	0.3	P
LI17	Replace Fluorescent Lamp with More Efficient Type, Building 4171 Warehouse:	10	0.8				0.8	0.4	0.5	P
LI18	Install Energy Efficient Lighting in Renovations, Building 4155 (under renovation) and other buildings	8.64	0.7				0.7	1	1.4	P
LI19[1]	Improve Lighting Efficiency in Hangars									A
BE1	Use transparent plastic panels behind glass sash, building 2233			2569	167		167	1052	6.3	K
BE2[2]	a. Reduce solar heat load by use of conventional solar[1] film OR					70	70	280	4	K
	b. spectrically selective solar film	28.8	2.3			70	72.3	630	8.7	K
BE3	Add vestibule on west side door of building 2233			137	8.9		8.9	105	11.8	K
BE4[3]	Use Light Shelves for Additional Natural Lighting[2] – Building 2233									K

ECM	ECM Description	Electrical Savings		Thermal Savings		Additional Savings ($K/yr)	Total Savings ($K/yr)	Investment ($K)	Simple Payback (yrs)	Location
		MWh/yr	$K/yr	MWh/yr	$K/yr					
BE5	Provide insulated panels for door openings in building 2222			28.3	1.84		1.84	16.8	9.1	K
BE6	Repair door seals, building 2226			9.7	0.63		0.63	2	3.2	K
BE7	Add vestibule on west side of building going-up ramp in building 2371			145	9.4		9.4	50.4	5.3	K
BE8	Place insulated panel in unused door areas in building 2371			51.8	3.4		3.4	7.2	2.1	K
BE9	Repair damaged doors in building 2371			9.7	0.6		0.6	1	1.6	K
BE10	Insulate north wall bldg 2371			49.8	3.2		3.2	22.5	7	K
BE11	Use transparent plastic panels behind glass windows building 2281			158	10.3		10.3	64.7	6.3	K
BE12	Use transparent plastic panels to replace roof skylights building 2281			118	7.7		7.7	70.4	9.2	K
BE13	Repair and insulate roof building 2281			372	24.2		24.2	149.6	6.2	K
BE14	Repair door seals, building 2370			9.6	0.6		0.6	2	3.2	K
BE15	Insulate roof in maintenance building #2226			44.8	2.9		2.9	32.8	11.3	K
BE16	Install Drop Ceiling in Certain Spaces, Building 4000			22	1.4		1.4	32.7	23.4	P
BE17	Close Opening Above Crane Using Brushes and Rubber Strips, Building 4000			19	1.2		1.2	1.6	1.3	P
BE18	Close Openings in Carpenter Storage Room, Building 4000			10	0.6		0.6	1	1.6	P
BE19	Add Wall Insulation, Building 4171			464	30.2		30.2	127	4.2	P
HV1[4]	Improve Building Heating Controls									K
HV2	Install Exhaust Fans To Ventilate Building 2233					116.64	116.6	65	0.6	K

ECM	ECM Description	Electrical Savings		Thermal Savings		Additional Savings ($K/yr)	Total Savings ($K/yr)	Investment ($K)	Simple Payback (yrs)	Location
		MWh/yr	$K/yr	MWh/yr	$K/yr					
HV3	Install Destratification Fans Recover Heat in Upper Strata – Building 2233			700	45.5		45.5	40	0.9	K
HV4	Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers 1 to 3			36.3	2.4		2.4	12	5.1	K
HV5	Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2233,			6.06	98.5		98.5	459.9	4.7	K
HV6	Reduce Excessive Air Use in Welding and Vehicle Exhaust Building 2233	46.4	3.7				3.7	7.5	2	K
HV7	Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,			95	6.2		6.2	33.95	5.5	K
HV8	Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,			24	15.6		15.6	97.9	6.3	K
HV9	Recirculate Exhaust Air Back into Booth During Drying Operations, Building 2225			59	3.8		3.8	20	5.2	K
HV10	Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2238			185.6	12.06		12.06	98.42	8.2	K
HV11	Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2239			283.5	18.43		18.43	145.5	7.9	K
HV12[5]	Improve System Efficiency in Tire Repair and Masking Area-Building 2255									K
HV13	Place Thermostat Controls Away From Occupants. Improved Control For Air Heaters	105	8.4				8.4	0.2	0.02	K
HV14[6]	Increase Ventilation to Reduce Solvent Fumes in Space-Building 2222							40		K
HV15	Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop Building 2225			76.5	4.4		4.4	31.75	7.2	K

ECM	ECM Description	Electrical Savings		Thermal Savings		Additional Savings ($K/yr)	Total Savings ($K/yr)	Investment ($K)	Simple Payback (yrs)	Location
		MWh/yr	$K/yr	MWh/yr	$K/yr					
HV16[7]	Provide Heaters over Doors on South Side-Building 2226							100		K
HV17	Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2226			120	7.8		7.8	54.5	7	K
HV18	Separate the Building Heating System from the Boiler and Connect the Building to District Heating System at Apprentice Shop, Building # 2364			~25%	~25%				< 5 yrs	K
HV19	Replace Warm Air Heaters with Hot Water Radiant Panels in Apprentice Shop, Building # 2363			75	4.9		4.9	39.3	8.1	K
HV20	Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop, Building # 2372			190	11.4		11.4	53.25	4.7	K
HV21	Have Heating Utility Turn off Heat to Buildings when not Warranted								Imme-diate	K
HV22	Use Heat from Generator Test for Building Heat, Building 2362			78	5.1		5.1	15	3	K
HV23	Provide Door Heater at Door on East Side of Building 2371			36	2.3		2.3	25	10.7	K
HV24	Provide Better Controls of H&V In Building 2371	365	29.2	600			29.2		0	K
HV25	Insulate Heating System Components-Building 2371								< 2 yrs	K
HV26	Provide Temperature Control Of Unit Heaters In Building 2281		0	180	11.7		11.7	7	0.6	K
HV27	Improve HVAC System Controls Building 4000		0	1000	65		65	150	2.3	P
HV28	Install Door Heater, Building 4155			13	0.8		0.8	25	29.6	P

ECM	ECM Description	Electrical Savings		Thermal Savings		Additional Savings ($K/yr)	Total Savings ($K/yr)	Investment ($K)	Simple Payback (yrs)	Location
		MWh/yr	$K/yr	MWh/yr	$K/yr					
HV29	Improve H&V System Controls and Air Movement In Building 4171, Pirmasens	105	8.4		26		34.4	20	0.6	P
HV30	Install Economizers, Building 4111, Pirmasens		0	799.2	40		40	90	2.3	P
HV-31[8]	Reduce Hot Water Temperatures—Building 4111 Pirmasens								immediate	P
HV32	Install Measurement Equipment, Building 4111	16.5	1.3	812.5	40.6		41.9	50	1.2	P
HV33[9]	Heating system improvement in Commissary at Katterbach Building 5805		-	45.3	3.7		3.7	22	5.9	P
HV34	Energy Retrofit in Gym-Building 5805									A
HV35	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5801			149	8.94		8.94	59.75	6.7	A
HV36	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5802			90	5.9		5.9	40	6.7	A
HV37	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5508	-		100	6		6	40	6.7	A
HV38	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5807		-	107	6.42		6.42	50	7.8	A
HV39	Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5806	-	-	80	4.8		4.8	62	12.9	A
HV40	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6500	-	-	269	16.14	-	16.14	79	4.9	A
HV41	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6501	-	-	142	8.52	-	8.52	45	5.3	A
HV42	Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6502	-	-	235	14.1	-	14.1	83	5.9	A

ECM	ECM Description	Electrical Savings MWh/yr	Electrical Savings $K/yr	Thermal Savings MWh/yr	Thermal Savings $K/yr	Additional Savings ($K/yr)	Total Savings ($K/yr)	Investment ($K)	Simple Payback (yrs)	Location
HV43[10]	Complex Energy Retrofit at Flight Simulator Building 6658, Illesheim									A
CEP1	Turn Off District Heating To Buildings In Summer			1019	47.9		47.9	20	0.4	K
EL1	Switch off Computers When Not In Use — Bldg 2233	36.8	2.9				2.9	0	0	K
EL2	Switch off Computers When Not In Use Building 4000	24.5	2				2	0	0	P
WS1	Elementary School: Heating System, Windows, Roof, Lighting, Walls, Solar Shading	17.2	2.5	3073	151.8		154.3	3592	23.3	WS
WS2	Middle School: Windows, Roof, Lighting, Walls, Solar Shading	8.6	1.2	1492	73.7		74.9	1765	23.6	WS

Note:

1.This ECM provides a holistic approach to lighting solution which includes reducing the number of lamps, changing the lamps to more energy effective and improve the illumination by treating the floor surfaces to be more reflective as in the Hangar 2, Katterbach. Pay-back in 2-3 yrs

2. Concept BE2a is recommended as more cost effective

3. Concept BE4 is not cost effective

4. HV1 Requires moderate investments resulting in up to 20% thermal energy savings with the payback within one heating season

5 This ECM will result in productivity improvement in summer and winter seasons. Requires further study with support from the shop management

6. Implementation of this ECM doesn't have economical justification but is strongly recommended for safety and health reason

7. Implementation of this ECM doesn't have economical justification but is strongly recommended for workers comfort reason

8. This no-cost ECM will reduced heat losses in the system with an immediate pay-back

9.Compex implementation of this ECM will reduce energy consumption and will result in improved thermal comfort, Short payback period.

10. This building has a significant potential for energy savings and improvement in thermal comfort and indoor air quality. Requires a Level II energy audit.

Annotation **K** referrers to ECM at Keiserslautern location, **P** – Pirmasens, **A** – Ansbach area and **WS** –Wiesbaden.

Appendix C: German Standards

This appendix contains explanations and an English version of some current German standards and guidelines concerning energy conservation, requirements to building envelope thermal characteristics and air tightness, heating and ventilation system. This appendix was prepared upon the request from IMA European Region and USACE, Europe District.

1 Thermal protection and power saving in buildings

The minimum requirements imposed to the thermal insulation of components and for restricting the annual heating requirement are defined according to EneG (energy saving law), WschV (heat insulation ordinance) and DIN 4108 (standards). The standards will provide thermal protection details for planning and performance of common rooms in buildings, which shall be heated to the standard indoor temperatures (≥19°C).

- Requirements for restricting the annual heating requirement as a function of A/V (ratio of the heat transferring enclosing surface A to the enclosed building volume V from A.

Table 1.1: Maximum values of the annual heating requirement depending on the heated building volume or the building active surface A_N as a function of A/V

A/V	Maximum annual heating requirement	
	Depending on building volume V, Q'_H [1]	Depending on building active surface A_N, Q''_H [2]
in m^{-1}	in $kWh/(m^3 a)$	in $kWh/(m^2 a)$
<=0,2	17,3	54,0
0,3	19,0	59,4
0,4	20,7	64,8
0,5	22,5	70,2
0,6	24,2	75,6
0,7	25,9	81,1
0,8	27,7	86,5
0,9	29,4	91,9
1,0	31,1	97,3
>=1,05	32,0	100,0

[1] $Q'_H = Q_H / V$

[2] $Q''_H = Q_H / A_N$

Q_H: annual heating requirement for one building

The values depending on the building active surface (table 1.1, column 3) shall be only used in case of buildings with an unobstructed height of 2,60 m or less.

- Minimum values for the heat flux resistances of non-transparent components

  - Requirements for single-layered or multi-layered massive components

  Table 1.2 shows the room limit values required by single components with a total mass depending on the surface of minimum 100 kg/m^2.

Table 1.2: Minimum values for the heat flux resistances of components

Line	Components		Heat reflux resistances R in (m^2 K)/W
1	Exterior walls; common rooms walls toward basement rooms: passages, open corridors, garages, ground		1,2[a]
2	Walls between external used rooms; flat walls		0,07
3	Stairwell walls	To stairwells with considerably lower indoor temperatures (e.g. indirectly heated stairwell); indoor temperature $\vartheta \leq 10°C$, stairwell shall be at least without frost	0,25
4		To stairwells with indoor temperature $\vartheta > 10°C$ (e.g. administrative buildings, commercials, school buildings, hotels, restaurants and residential building)	0,07
5	Flat walls, ceilings between external workrooms; ceilings underneath rooms between insulated conical roofs and walls in adjacent rooms in case of completed attics	In general	0,35
6		In central heated office buildings	0,17
7	Under closure common rooms without basement	Directly at the ground up to a room depth of 5 m	0,90
8		Above a non-ventilated hollow space adjacent to the ground	
9	Ceilings underneath non-completed attics; ceilings underneath rooms which allows creeping and rooms which are still smaller; ceilings underneath ventilated rooms between conical roofs and walls in adjacent rooms in case of completed attics, insulated conical roofs		
10	Basement ceiling, ceiling toward closed, unheated corridors and others		
11 / 11.1	ceilings (also roofs) which isolate the common rooms from the ambient air	down, towards garages (also heated), passages (also closable) and creep basement capable to ventilating[b]	1,75
11 / 11.2		upwards, roofs and ceilings underneath terraces etc.	1,2

[a] For buildings with lower indoor temperatures $(12°C \leq \vartheta > 19°C)$: R = 0,55 (m^2 K)/W
[b] Increased heat flux resistances because of foot coldness.

-Requirements for lightweight and skeleton components

Increased requirements will apply to exterior walls, ceilings underneath non-completed attics and roofs with a total mass depending on the surface of less than 100 kg/m^2 with a minimum value of the heat reflux resistance R >=1,75 (m^2 K)/W. In case of the skeleton components, the requirements are only valid for the space between frameworks. In these cases for the total component an average R=1,0 (m^2) shall be observed. The same value will apply to the shatter boxes. For the lid of the shatter boxes the value of R=0,55 (m^2 K)/W shall be observed.

The non-transparent part of the framework space of the window walls and wings, which account for more than 50% of the total framework surface, must fulfill at least the requirements according to table 2. In the case of surface shares of less than 50% the heat reflux resistances must be R>=1,0 ((m^2 K)/W).

- Limitation of the heat reflux in case of panel heating system
  In case of panel heating system the heat-transfer coefficient of the layer components between the heating area and the ambient air, the ground or the building parts with significantly low indoor temperatures shall not exceed the value of 0,35 W/(m^2 K).

- Requirement of radiators in front of the windows
  By arranging the radiators in front of external window areas, the heat-transfer coefficient of these components shall not exceed the value 1,5 W/(m^2 K).

- Simplified detection procedure
  For small residential buildings up to 2 floors and up to 3 apartments the maximum values of the heat-transfer coefficient k showed in table 3 shall not be exceeded.

Table 1.3: Requirements to the heat-transfer coefficient for single exterior components of the heat transferring enclosing surface A in case of smaller residential buildings

Line	Component	Max. heat-transfer coefficient k_{max} in W/(m^2 K)
1	Exterior walls	$k_W \leq 0,50^{1)}$
2	External windows , window wings and roof windows	$k_{m,Feq} \leq 0,70^{2)}$
3	Ceilings underneath non-completed attics and roofs (including conical roofs), which isolate rooms upwards and downwards from the ambient air	$k_D \leq 0,22$
4	Basement ceilings, walls and ceilings towards unheated rooms, ceilings and walls adjacent to the ground	$k_G \leq 0,35$

1) The requirement is fulfilled if the brickwork with a wall thickness of 36,5 cm is executed by building materials with a heat conductivity of $\lambda \leq 0,21$ W/(m K)
2) The average equivalent heat-transfer coefficient $k_{m.Feq}$ shall correspond to a heat-transfer coefficient averaged by all exterior windows and window wings.

- Requirements for limiting the annual transmission heat demand in constructed buildings with low indoor temperature
  $(12°C \leq \vartheta > 19°C)$

Table 1.4 will show the maximum values as a function of the value A/V of the specific annual transmission heat demand depending on the heated building volume that shall not be exceeded.

Table 1.4: Values of the annual transmission heat demand Q'_T depending on the heated building as a function of the ratio A/V

A/V in m^{-1}	Q'_T in $kWh/(m^3 a)$ [1)]
<= 0,20	6,20
0,30	7,80
0,40	9,40
0,50	11,00
0,60	12,60
0,70	14,20
0,80	15,80
0,90	17,40
>= 1,00	19,00
[1)] Interim values are determined by the following equation $Q'_T = 3,0 + 16(A/V)$ in $kWh/(m^3 a)$	

2 Heating System

- Construction material classes (acc. to DIN 4102-1)

The construction materials are classified into the construction material classes according to its fire behavior.

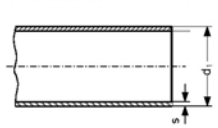
Table 2.1: Construction material classes

Construction material classes	Building inspection definition
A A1 A2	Incombustible materials
B B1 B2 B3	Combustible materials Flame resistant materials Normal inflammable materials Easily inflammable materials

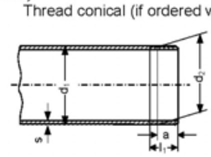
- DIN 2440 Threaded pipes (withdrawn)
  This standard will apply for medium-heavy threaded pipes. They shall be appropriated to a nominal pressure 25 for liquidity and a nominal pressure 10 for air and harmless gases.

  Dimensions, designation (dimensions in mm)

Rule model



Thread conical (if ordered with thread)



Designation of a medium-heavy threaded pipe nominal diameter 40, seamless zinc-coated (B), producer length:

Table 2.2: Threaded pipes DIN 2440 – DN 40 – seamless zinc-coated B

Nominal diameter DN	Nominal diameter connection of the fittings	Whitworth-pipe thread	Pipe: Outer diameter d_1	Pipe: Wall thickness s	Pipe: Weight: Of the smooth pipe kg/m	Pipe: Weight: Of the pipe with bushing[1)] kg/m	Thread: Theoretical pipe diameter d_2	Thread: Turn number based on 25,4 mm	Thread: Serviceable thread length l_1 min. in case of a max.	Thread: Distance of the thread diameter d_2 from pipe end a max.	Thread: Distance of the thread diameter d_2 from pipe end a min.	Respective bushing: Outside diameter min.	Respective bushing: length min.
6	1/8	R 1/8	10,2	2,0	0,407	0,410	9,278	28	7,4	4,9	3,1	14	17
8	¼	R 1/4	13,5	2,35	0,650	0,654	13,157	19	11,0	7,3	4,7	18,5	25
10	3/8	R 3/8	17,2	2,35	0,852	0,858	16,662	19	11,4	7,7	5,1	21,3	26
15	½	R 1/2	21,3	2,65	1,22	1,23	20,955	14	15,0	10,0	6,4	26,4	34
20	¾	R 3/4	26,9	2,65	1,58	1,59	26,441	14	16,3	11,3	7,7	31,8	36
25	1	R 1	33,7	3,25	2,44	2,46	32,249	11	19,1	12,7	8,1	39,5	43
32	1 1/4	R 1 1/4	42,4	3,25	3,14	3,17	41,910	11	21,4	15,0	10,4	48,3	48
40	1½	R 11/2	48,3	3,25	3,61	3,65	47,803	11	21,4	15,0	10,4	54,5	48
50	2	R 2	60,3	3,65	5,10	5,17	59,614	11	25,7	18,2	13,6	66,3	56
65	2½	R 2 ½	76,1	3,65	6,51	6,63	75,184	11	30,2	21,0	14,0	82	65
80	3	R 3	88,9	4,05	8,47	8,64	87,884	11	33,3	24,1	17,1	95	71
100	4	R 4	114,3	4,5	12,1	12,4	113,030	11	39,3	28,9	21,9	122	83
125	5	R 5	136,7	4,85	16,2	16,7	138,430	11	43,6	32,1	25,1	147	92
150	6	R 6	165,1	4,85	19,2	19,8	163,830	11	43,6	32,1	25,1	174	92

[1)] Depending on an average length of 6 m

Type: seamless or welded

Mode of supply: In factory lengths without thread and without bushing.
In case of another mode of supply, the designation shall be completed as follows:
In case of supply with conical thread on both ends: with thread
In case of supply with conical thread on both ends and with a screwable bushing: with bushing

Surface treatment

The pipes will be provided in following types according to the respective order:

Table 2.3

Surface		abbreviation
Black		-
Black, appropriate for zinc coating		A
Coated with zinc		B
Non metallic protective coating[2)]	Outside	C
	Inside	D
[2)] by arrangement		

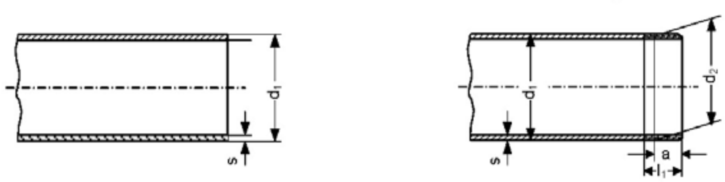
- Seamless steel pipes acc. to DN 50 (DIN EN 10216 part 1)

This part of the EN 10216 will contain the technical supply conditions for two qualities, TR1 and TR2, seamless pipe with round profile made out of soft steel with fixed room temperature properties.

This standard will contain the ordering details, the manufacturing process (pipe manufacturing and supply condition), requirements (chemical composition, mechanical properties, and measures, masses depending on the length and boundary deviations), test procedures etc.

- DIN 2441 Threaded pipes (withdrawn)
  This standard will apply for heavy threaded pipes. They shall be appropriated to a nominal pressure 25 for liquidity and a nominal pressure 10 for air and harmless gases.

  Dimensions, designation (dimensions in mm)
  Rule model Thread conical (if ordered with thread)



Designation of a medium-heavy threaded pipe nominal diameter 40, seamless zinc-coated (B), manufacturer's length:

Table 2.4 Threaded pipes DIN 2441 – DN 40 – seamless B

Nominal diameter	Nominal diameter connection of the fittings	Whit-worth-pipe thread	Pipe				Thread					Respective bushing	
			Outer diameter d_1	Wall thickness s	Weight: Of the smooth pipe	Weight: Of the pipe with bushing[1]	Theoretical pipe diameter d_2	Turn number based on 25,4 mm	Service able thread length l_1 min. in case of a	Distance of the thread diameter d_2 from pipe end a	Distance of the thread diameter d_2 from pipe end a	Out side diameter	length
DN					kg/m	kg/m			max.	max.	min.	min.	min.
6	1/8	R 1/8	10,2	2,65	0,493	0,496	9,278	28	7,4	4,9	3,1	14	17
8	¼	R 1/4	13,5	2,9	0,769	0,773	13,157	19	11,0	7,3	4,7	18,5	25
10	3/8	R 3/8	17,2	2,9	1,02	1,03	16,662	19	11,4	7,7	5,1	21,3	26
15	½	R 1/2	21,3	3,25	1,45	1,46	20,955	14	15,0	10,0	6,4	26,4	34
20	¾	R 3/4	26,9	3,25	1,90	1,91	26,441	14	16,3	11,3	7,7	31,8	36
25	1	R 1	33,7	4,05	2,97	2,99	32,249	11	19,1	12,7	8,1	39,5	43
32	1 1/4	R 1 1/4	42,4	4,05	3,84	3,87	41,910	11	21,4	15,0	10,4	48,3	48
40	1½	R 11/2	48,3	4,05	4,43	4,47	47,803	11	21,4	15,0	10,4	54,5	48
50	2	R 2	60,3	4,5	6,17	6,24	59,614	11	25,7	18,2	13,6	66,3	56
65	2½	R 2 ½	76,1	4,5	7,90	8,02	75,184	11	30,2	21,0	14,0	82	65
80	3	R 3	88,9	4,85	10,1	10,3	87,884	11	33,3	24,1	17,1	95	71
100	4	R 4	114,3	5,4	14,4	14,7	113,030	11	39,3	28,9	21,9	122	83
125	5	R 5	136,7	5,4	17,8	18,3	138,430	11	43,6	32,1	25,1	147	92
150	6	R 6	165,1	5,4	21,2	21,8	163,830	11	43,6	32,1	25,1	174	92

[1] Depending on an average length of 6 m

Type: Seamless or welded

Mode of supply: In manufacturer's lengths without thread and without bushing.
In case of another mode of supply, the designation shall be completed as follows:
In case of supply with conical thread on both ends: with thread
In case of supply with conical thread on both ends and with a screwable bushing: with bushing

Surface treatment

The pipes will be provided in following types according to the respective order:

Table 2.5

Surface		abbreviation
Black		-
Black, appropriate for zinc coating		A
Coated with zinc		B
Non metallic protective coating[2]	Outside	C
	Inside	D

[2] by arrangement

DIN EN 10255: Replacement for DIN 2440 and DIN 2441 !

This document shall define the requirements on round pipes made out of mild steel that are appropriate to welding and threading and provides a set of options for the pipe quality and for the coatings. This document shall apply to pipes with a nominal outer diameter from 10,2 mm to 165,1 mm (thread size 1/8 to 6) for two series, middle and heavy line and to 3 other pipe types with fixed wall thickness.

This standard will contain the ordering designation, the manufacturing process (pipe manufacturing and supply condition), requirements (chemical composition, mechanical properties, and measures, masses depending on the length and boundary deviations), test procedures etc.

- DIN 2394: (withdrawn)

DIN EN 10305 part 3: Replacement for DIN 2394

This part of the EN 10305 will contain the technical supply conditions for welded rolled steel precision pipes with round profiles.
Pipes according to this part of EN 10305 are characterized by precisely defined boundary deviations and a fixed surface finish. Typical applications areas are the vehicle construction, the furniture industry and the general engineering.
This standard will contain the ordering designation, the manufacturing process (pipe manufacturing and supply condition), requirements (chemical composition, mechanical properties, and measures, masses depending on the length and boundary deviations), test procedures etc.

- Selection of Radiators

- Dimensioning (VDI 6030): (to enclose)
- Heat capacity tested (DIN EN 442): (to enclose)

- Selection of thermostat valves and thermostat heads: (to enclose)
- The heating system shall be balanced acc. to DIN 18 380. (note: the standard was completely revised)

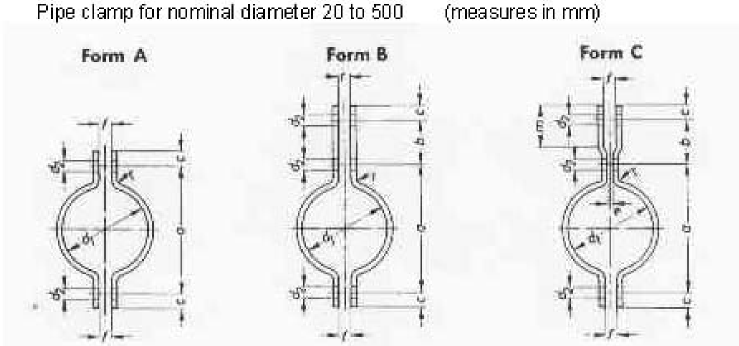
- DIN 4109 (DIN 4109 supplementary sheet 2) (Sound Insulation)

The details for the sewage pipe will apply analogously as for the piping of the heating system.

The flow processes appearing at the sewage discharge, especially at the sewage connections and in case of changes of direction, will activate the sewage pipe to mechanical vibrations, which will be transmitted themselves at the walls with the fixed pipes.
The following means for noise reduction will be available (apart from constructional means):
- The sewage pipes shall not be led open at walls in rooms requiring a high sound insulation
- The pipe routing will require a structure-borne sound insulation
- Prevention of drastic changes of direction

- DIN 3567

Pipe clamp for nominal diameter 20 to 500 (measures in mm)



Designation of a pipe clamp form B with a clear diameter d_1 = 89 mm:
Pipe clamp B 89 DIN 3567

Appropriates nuts shall be commanded particularly.

d_1 [1]	Applicable in case of nominal diameter		Pipe clamp								Flat steel acc. to DIN 1017	Appropriates hexagon bolts acc. to DIN 601	weight (7,85 kg/dm^3) kg/100 piece form	
			a	b [2]	c	d_2	e	f	m	r			A	B und C
25	20		62	46	15	11,5	4	7	44	4	30x5	M10x30Mu	21,37	31,79
27		¾''	66										22,57	32,95
30	25		68										23,37	33,68
34		1''	72										24,79	35,15
38	32		76										26,12	36,57
43		11/4''	82										27,87	38,36
45	40		84										28,81	39,17
49		11/2''	88										30,37	40,72
57	50		104	54	18	14	4	9	52	6	40x6	M12x35Mu	56,10	76,65
61		2''	108										58,20	77,99
77	65	21/2''	122										66,30	85,95
89	80	3''	136										75,30	95,09
108	100		172	70	24	18	5	11	68	6	50x8	M16x45Mu	159,10	203,00
115		4''	178										163,40	206,51
133	125		196										178,50	220,00
140			204										183,10	225,93
159	150		222										200,00	240,00
169			232										208,10	252,40
191	(175)		254										239,40	282,32
194			258										242,00	273,00
216	200		280										260,00	301,00
220			284										264,40	308,90
267	250		342	86	30	23	6	14	84	8	60x8	M20x50Mu	385,00	445,00
273			348										390,60	452,12
318	300		392										440,00	500,00
324			398										448,80	511,30
356	350		432										508,70	571,66
368			444										530,00	600,00
407	400		498	104	36	27	7	18	98	8	70x10	M24x60Mu	852,20	963,39
419			510										875,00	980,00
508	500		600										1020,00	1139,00
521			614										1050,00	1160,00

[1] Approximately identically to the outer diameter of the appropriate pipe.

[2] The indicated measures b shall be minimum dimensions. Dimensions varying from the table shall be indicated by ordering; the designation is for a pipe clamp form B with a clear diameter d_1 = 89 mm and e.g. b = 60mm: **pipe clamp B 89 x 60 DIN 3567**

Sizes in brackets shall be avoided.

- EnEV (energy saving ordinance)

EnEV annex 5: Requirements for restricting the heat output of the heating and hot water pipes and fittings.

The heat output of the heating and hot water pipes and fittings shall be limited by thermal insulation according to table 2.6.

Table 2.6: Thermal insulation of heating and hot water pipes and fittings

Line	Type of pipes/fittings	Min. insulation layer thickness depending on the thermal conductivity of 0,035 W/(m K)
1	Internal diameter up to 22 mm	20 mm
2	Internal diameter over 22 mm 35 mm	30 mm
3	Internal diameter over 35 mm up to 100 mm	Equal internal diameter
4	Internal diameter over 100 mm	100 mm
5	Pipes and fittings acc. to the lines 1 up to 4 at wall and ceiling penetrations, at pipes cross, at pipes joints, at central piping distributions	1/2 of the requirements acc. to lines 1 up to 4
6	Pipes of central heating plants acc. to lines 1 up to 4, that should be run acc. to the commencement of this ordinance in components between heated rooms of different users.	1/2 of the requirements acc. to the lines 1 up to 4
7	Pipes acc. to the line 6 in the floor construction	6 mm

If pipes of central heating plants acc. to the lines 1 up to 4 in heated rooms or in components between heated rooms of an user exist and if its heat output can be influenced by led open shut-offs, no requirements on the min. insulation layer thickness will be requested. That shall apply as well to hot water piping in apartments up to an internal diameter of 22 mm, which are not included in the circulation and not equipped with an electrical tracer heating.

In case of materials with a thermal conductivity different from 0,035 W/(m K), the min. insulation layer thickness shall be converted analogously. For the conversion and the thermal conductivity, the arithmetic techniques and the arithmetic values in the rules of techniques shall be used.

In case of the heating and hot water pipes the min. insulation layer thicknesses acc. to table 1 should be only allowed to be reduced if an equivalent limitation of heat output will be secured in case of other pipe insulation structures and with consideration of the insulation effect of the piping walls.

3 Ventilation System

- DIN 24145 and DIN 24146: withdrawn
- DIN 1949: nothing to do with "wall thickness"
- DIN 18017

- Individual exhaust ventilation systems with own exhaust air lines: These exhaust ventilation systems are equipped per apartment with one exhaust line in the outside (fig. 3-1)

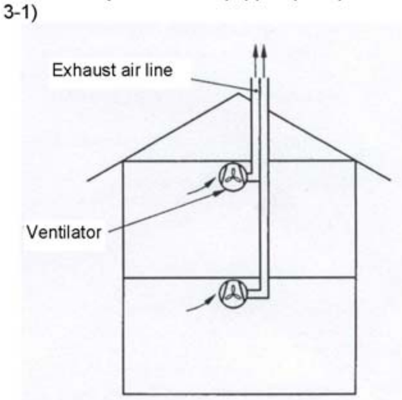


Fig. 3-1 Individual exhaust ventilation systems with own exhaust air lines.

- Individual exhaust ventilation systems with collective exhaust air lines: These exhaust ventilation systems are equipped for many apartments with an collective exhaust line (principal line), charging the exhaust air under overpressure (fig.3-2)

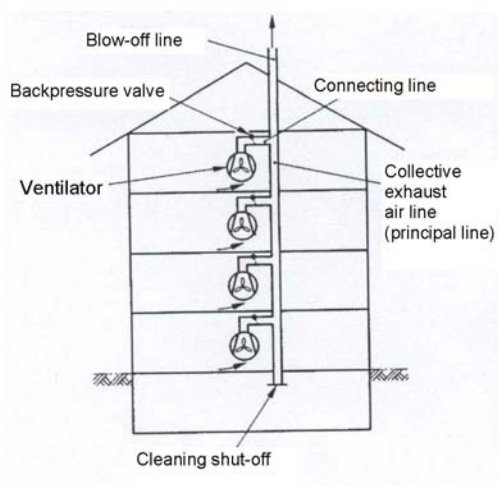


Fig. 3-2 Individual exhaust ventilation systems with collective exhaust air line (principal line)

- DIN 4109

The VDI 2081 shall be considered for design and realization of the measures for sound reduction (VDI 2081-1and -2 enclose)

- LBO-(BW) Landesbauordnung für Baden-Württemberg (building code of Baden-Wuerttemberg)

§ 31 Ventilation systems, installation shafts and ducts

(1) Ventilation systems shall be fail-safe and fireproof. They should not affect the correct operating of the fireplaces. They must be placed and manufactured in the way that they cannot transport odors and dust to other rooms. The sound conduction in external rooms must be sufficiently insulated.

(2) For installation shafts and ducts shall apply analogously paragraph 1.

- NFPA: English version
- UFC 3-600-01: English version

Requirements to the air tightness of building envelope components

- **DIN 4108-2**

The joint permeability coefficient concerning the connection joints of the building components resulting from measurements must be lass than 0,1 m^3/mh (daPa $^{2/3}$).

In case of windows and window doors the requirements acc. to DIN 18055 shall be applied. In case of outer doors the joint permeability coefficient must be a <=2,0 m^3/mh (daPa $^{2/3}$).

- **DIN 4108-7**

If measurements of the air tightness of buildings ore building components are made, the measured air volume flow considering the pressure difference between inside and outside of 50 Pa

- in case of buildings without HVAC systems:
  - depending on the air volume should not exceed $3h^{-1}$
  - depending on the net base-area should not exceed 7,8 $m^3/(m^2\ h)$
- in case of buildings with HVAC system (also exhaust air installation):
  - depending on the air volume should not exceed $1{,}5h^{-1}$
  - depending on the net base-area should not exceed 3,9 $m^3/(m^2\ h)$

The requirements depending on the volume shall be generally applied. In case of buildings or building components with the clear height between floors is 2,6 m or less, the requirement values depending on the net base-area can be used alternatively.

- **WSchV**

Table: joint permeability coefficients for outside window and window doors as well as for outer doors (requirement categories acc. to DIN 18055)

		Joint permeability coefficient a in m^3/mh (daPa$^{2/3}$)	
	Number of floors	A	B und C
1	Buildings up to 2 complete floors	2,0	-
2	Buildings with more than 2 complete floors	-	1,0
1) requirement categories A: building height up to 8 m B: building height up to 20 m C: building height up to 100 m			

ICS 91.140.10 VDI-RICHTLINIEN Juli 2002 / July 2002

VEREIN DEUTSCHER INGENIEURE	Auslegung von freien Raumheizflächen Grundlagen Auslegung von Raumheizkörpern Designing free heating surfaces Fundamentals Designing of heating appliances	VDI 6030 **Blatt 1 / Part 1** **Ausg. deutsch/englisch** **Issue German/English**

Frühere Ausgabe: 04.99 Entwurf, deutsch
Former edition: 04.99 draft, in German only

Die deutsche Version dieser Richtlinie ist verbindlich.

No guarantee can be given with respect to the English translation. The German version of this guideline shall be taken as authoritative.

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VDI-Gesellschaft Technische Gebäudeausrüstung (TGA)

VDI/DIN-Handbuch Wärme-/Heiztechnik

Vorbemerkung

Diese VDI-Richtlinie soll angewendet werden bei der Auslegung von freien Raumheizflächen für Warmwasserheizungen. Es werden Regeln aufgestellt für die Bestimmung der Ansichtsabmessungen, der Vorlauf- und Rücklauftemperatur, des Wasserstroms und der Normleistung der jeweils ausgewählten freien Raumheizfläche.

Die Richtlinie soll dem Architekten den Zusammenhang zwischen Raumgestaltung und Erfordernissen der freien Heizflächen aufzeigen; dem Planer und Anlagenersteller soll sie die Grundlage liefern für die Abstimmung der Raumheizflächen auf das Baukonzept und die Anforderungen aus der Raumnutzung. Damit ist die Richtlinie auch eine Hilfe für den Auftraggeber, seine Vorstellungen und Wünsche ausreichend detailliert anzugeben.

Mit der Richtlinie wird daher das Ziel verfolgt, den Umfang der Auslegung mit den Anforderungen des Auftraggebers in Einklang zu bringen. Das bedeutet, dass mit der Auslegung mehrere Funktionen der freien Raumheizflächen festgelegt werden: Neben der Deckung der Heizlast sollen sie mögliche Behaglichkeitsdefizite[1)] dadurch mindern oder beseitigen, dass äußere Umfassungsflächen des zu beheizenden Raumes erwärmt oder die durch kältere Flächen hervorgerufenen Strahlungsdefizite kompensiert und Fallluftströmung beseitigt werden. Hierbei handelt es sich um Funktionen, die durch Messung prinzipiell nachweisbar sind. Weitere Funktionen können die Erfüllung ästhetischer Ansprüche und zusätzlich die Nutzung der freien Raumheizflächen z. B. als Handtuchhalter, Garderobe, Raumteiler u.ä. sein.

Damit liefert die Richtlinie auch die Grundlage für einen Vergleich von Planungsvarianten, indem sie die Definition eindeutiger Funktionsforderungen (nach Art und Umfang) ermöglicht. Um die anlagentechnischen Unterschiede bei Planungsvarianten für freie Raumheizflächen zu verdeutlichen, wird die Wirkung von Heizflächenfunktionen, die Behaglichkeitsdefizite beseitigen, durch die herstellbare Anforderungszone im Raum und die Anforderungsstufe beschrieben. Sie präzisiert die Vorschriften zur Dimensionierung der Heizflächen nach DIN pr EN 12 828 und stellt daher eine Anleitung dar, die Anforderungen dieser Norm für die Anwendung umzusetzen.

Allen ehrenamtlichen Mitarbeitern an dieser VDI-Richtlinie sei auf diesem Wege gedankt.

1) Zum Zwecke der Auslegung freier Raumheizflächen eingeführte Definition

Preliminary note

This VDI-guideline is intended for use in the designing of free heating surfaces for water-based heating systems. The guideline specifies rules for the determination of the visible-surface dimensions, the inlet and outlet water temperatures, the water flow rate, and the standard thermal output of the selected free heating surface.

For the architect, this VDI-guideline serves to illustrate the interaction between the room design and the requirements to be met by the free heating surfaces. For the planner and heating-system manufacturer, it establishes a basis for tailoring free heating surfaces in a room to the building concept, and to the requirements arising from the use of the room. It is, therefore, also an aid to the orderer, in specifying his ideas and desires to sufficient detail.

This VDI-guideline, therefore, aims at matching the scope of designing with the orderer's requirements. This means that in the process of designing, several functions of the free heating surfaces are specified: In addition to covering the heating load, they also serve to reduce or compensate possible deficits in comfort[1)] by heating up exterior surfaces enclosing the room to be heated, or by compensating radiation deficits due to colder surfaces, and by eliminating downdrafts. In principle, these functions can be verified by measurements. Further functions may include the fulfilling of aesthetic requirements and the additional use of free heating surfaces for the purpose of, e. g., hanging towels or clothes, partitioning a room, etc.

In consequence, by defining clear functional requirements (according to type and scope), this VDI-guideline also provides a basis for comparing design variants. In order to emphasize the system-dependent differences between design variants for free heating surfaces, the effects of heating-surface functions which serve to compensate deficits in comfort are described in terms of the requirements zone achievable in the room, and the class of requirements. In this guideline, the provisions of DIN pr EN 12 828 for the dimensioning of heating surfaces are covered in greater detail, thus offering guidance on achieving compliance with the requirements of this standard in practical applications.

VDI wishes to express its thanks to all those experts who contributed, by way of honorary work, to drafting this guideline.

1) This definition has been introduced fort he purposes of designing free heating surfaces.

1 Geltungsbereich und Zweck

Diese VDI-Richtlinie gilt für die Auslegung von freien Raumheizflächen für Warmwasserheizungen in Wohn-, Büro- und anderen Gebäuden mit Aufenthaltsräumen, die ähnlich genutzt werden. Zweck der Richtlinie ist es, ein Anforderungsprofil aufzustellen, das Ansprüche in Hinblick auf Komfort und sparsamen Energieeinsatz umfasst und damit deutlich über den Einfachanspruch, nur die Normheizlast zu decken, hinausgeht. Drei verschiedene Anforderungsstufen erlauben es, bedarfsangepasst den Umfang der Funktionen der auszulegenden freien Raumheizfläche festzulegen und auch zu begrenzen. Damit soll verhindert werden, dass generell die höchste Anforderungsstufe beansprucht werden kann. Auch soll die Einschränkung auf freie Raumheizflächen nicht ausdrücken, dass andere Raumheizsysteme die hier angeführten Anforderungsstufen nicht erreichen. Die Beeinflussung von Luftströmungen im Raum durch maschinelle Lüftung ist nicht Gegenstand dieser Richtlinie.

Die Auslegungsrechnung wird in diesem Blatt am Beispiel der Raumheizkörper gezeigt.

Die Auslegung beinhaltet

- in einem ersten Schritt die Festlegung des Anbringungsortes des Raumheizkörpers, die Typauswahl für den vorliegenden Zweck, die Festlegung der Ansichtsabmessungen und die Berechnung der mittleren Heizflächenübertemperatur,
- in einem zweiten Schritt die Berechnung der Vor- und Rücklauftemperatur, des Wasserstroms und der Norm-Wärmeleistung des Raumheizkörpers unter Beachtung der Normheizlast und einer vorgegebenen Aufheizreserve,
- in einem dritten Schritt die Auswahl des erforderlichen Heizkörpermodells.

1 Scope and purpose

This guideline applies to the designing of free heating surfaces for water-based heating systems in residential, office and other buildings where day rooms are used similarly. This guideline aims at establishing a set of requirements including comfort and efficient use of energy, which means exceeding the simple aim of just covering the required design heating load. Three different classes of requirements allow determining, and limiting, the scope of functions of the free heating surface to be designed, depending on the application. This serves to avoid that the highest class can be claimed as a matter of principle. The restriction to free heating surfaces is not intended to indicate that other room heating systems do not achieve the classes of requirements described here.

The effect of forced ventilation by means of fans on the air flow in a room is not covered in this guideline.

Designing includes the following steps:

- firstly, the determination of the location where the free heating surface is to be installed, selection of the appropriate type, dimensioning of the visible surfaces, and the calculation of the mean heating-surface excess temperature,
- secondly, the calculation of the inlet and outlet water temperatures, water flow rate, and standard thermal output of the heating surface, taking into account the design heating load and a specified heating-up reserve
- thirdly, the selection of the appropriate heating-appliance model.

2 Zugehörige Vorschriften, Normen und Richtlinien

Vorschriften

WärmeschutzV	Verordnung über einen energiesparenden Wärmeschutz von Gebäuden, ersetzt durch EnEV
TRGI	Technische Regeln für Gas-Installation
FeuVO	Feuerungsverordnungen der Länder

Normen

DIN 18 017-1	Lüftung von Bädern und Spülaborten ohne Außenfenster; Einzelschachtanlagen ohne Ventilatoren
DIN 18 017-3	Lüftung von Bädern und Toilettenräumen ohne Außenfenster mit Ventilatoren
DIN 1946-2	Raumlufttechnik; Gesundheitstechnische Anforderungen (VDI-Lüftungsregeln)
DIN 1946-6	Raumlufttechnik; Lüftung von Wohnungen; Anforderungen, Ausführung, Abnahme
DIN 4108-4	Wärmeschutz im Hochbau; Wärme- und feuchteschutztechnische Anforderungen
DIN 4701-1	Regeln für die Berechnung des Wärmebedarfs von Gebäuden; Grundlagen der Berechnung
DIN 4701-2	– ; Tabellen, Bilder, Algorithmen
DIN 4701-3	– ; Auslegung der Raumheizeinrichtungen
DIN 4703-3	Raumheizkörper; Umrechnung der Normwärmeleistung
DIN EN 442-1	Radiatoren, Konvektoren; Technische Spezifikationen und Anforderungen
DIN EN 442-2	Radiatoren, Konvektoren; Prüfverfahren und Leistungsangabe
DIN EN 12 207	Fenster und Türen; Luftdurchlässigkeit, Klassifizierung

2 References to regulations, standards and guidelines

Regulations

WärmeschutzV	Ordinance on energy-saving heat insulation in buildings, replaced by EnEV
TRGI	Technical rules for gas installations
FeuVO	Firing ordinances of the countries

Standards

DIN 18 017-1	Ventilation of bathrooms and WCs without outside windows; single shaft systems without ventilators
DIN 18 017-3	Ventilation of bathrooms and WCs without outside windows by fans
DIN 1946-2	Ventilation and air conditioning – Part 2: Technical health requirements (VDI ventilation code of practice)
DIN 1946-6	Ventilation and air conditioning – Part 6: Ventilation for residential buildings; requirements, performance, acceptance (VDI ventilation code of practice)
DIN 4108-4	Thermal insulation and energy economy in buildings – Part 4: Characteristic values relating to thermal insulation and protection against moisture
DIN 4701-1	Rules for calculating the heat requirement of buildings – Part 1: Basic rules for calculation
DIN 4701-2	Rules for calculating the heat requirement of buildings – Part 2: Tables, pictures, algorithms
DIN 4701-3	Rules for calculating the heat requirement of buildings – Part 3: Design of space heaters
DIN 4703-3	Heating appliances – Part 3: Conversion of the standard thermal output
DIN EN 442-1	Radiators and convectors – Part 1: Technical specifications and requirements
DIN EN 442-2	Radiators and convectors – Part 2: Test methods and rating
DIN EN 12 207	Windows and doors – Air permeability – Classification

DIN pr EN 12 828 Heizungssysteme in Gebäuden; Planung und Installation von Warmwasser-Heizungsanlagen

DIN pr EN 12 831 Verfahren zur Berechnung der Norm-Heizlast

DIN EN ISO 7730 Gemäßigtes Umgebungsklima – Ermittlung des PMV und des PPD und Beschreibung der Bedingungen für thermische Behaglichkeit

Richtlinien

VDI 2067 Blatt 20: 2000-08 Wirtschaftlichkeit gebäudetechnischer Anlagen; Energieaufwand der Nutzenübergabe bei Warmwasserheizungen. Berlin: Beuth Verlag

DIN pr EN 12 828 Heating systems in buildings – Design and installation of water based heating systems

DIN pr EN 12831 Heating systems in buildings – Method for calculation of the design heating load

DIN EN ISO 7730 Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort (ISO 7730:1994)

Guidelines

VDI 2067 Part 20: 2000-08 Economic efficiency of building installations – Energy effort of benefit transfer for water heating systems. Berlin: Beuth Verlag

3 Begriffe, Formelzeichen[2)]

Formelzeichen

Abkürzung	Bezeichnungen	Einheit
A_{Fe}	Fensterfläche	m^2
A_{HK}	Ansichtsfläche des Heizkörpers	m^2
A_U	Umfassungsfläche	m^2
a_{krit}	Kritische Fugendurchlässigkeit	$m^3/(mh)$
b	Beimischwert (vereinfachtes Heizkörper-Modell)	–
c_p	spezifische Wärmekapazität	J/(kgK)
$e_{1,max}$	Maximal zugelassene Aufwandszahl der Nutzenübergabe nach VDI 2067 Bl. 20	–
H_{Fe}	Fensterhöhe	m
H_{HK}	Bauhöhe des Heizkörpers	m
L_{Fe}	Fensterlänge	m
L_{HK}	Gesamtlänge des Heizkörpers	m
n	Heizkörperexponent	–
p_0	Bezugs-Luftdruck	kPa
$\dot{Q}_N$	Normheizlast (nach DIN 4701 bzw. DIN pr EN 12 831)	W
q_m	Wasserstrom	kg/s
q_{mS}	Norm-Wasserstrom	kg/s
t_1	Vorlauftemperatur	°C
t_2	Rücklauftemperatur	°C

[2)] abgestimmt auf DIN EN 442-2

3 Terms, symbols[2)]

Symbol	Meaning	Unit
A_{Fe}	window area	m^2
A_{HK}	visible-surface area of heating appliance	m^2
A_U	enclosing-surface area	m^2
a_{krit}	critical joint permeability	$m^3/(mh)$
b	mixing coefficient (simplified heating-appliance model)	–
c_p	specific heat capacity	J/(kg/K)
$e_{1,max}$	maximum permissible effort number for benefit transfer as per VDI 2067 Part 20	–
H_{Fe}	height of window	m
H_{HK}	overall height of heating applicance	m
L_{Fe}	length of window	m
L_{HK}	overall length of heating applicance	m
n	heating-appliance exponent	–
p_0	reference air pressure	kPa
$\dot{Q}_N$	design heating load (as per DIN 4701 or DIN pr EN 12831)	W
q_m	water flow rate	kg/s
q_{mS}	standard water flow rate	kg/s
t_1	inlet water temperature	°C
t_2	outlet water temperature	°C

[2)] harmonized with DIN EN 442-2

t_r	Bezugs-Lufttemperatur	°C
t_m	mittlere Wassertemperatur	°C
U_{Fe}	Wärmedurchgangskoeffizient des Fensters (früher k_{Fe})	W/(m²K)
U_U	Wärmedurchgangskoeffizient der Umfassungsfläche	W/(m²K)
σ_{Ausl}	Spreizung zwischen Vor- und Rücklauftemperatur	K
Φ	Wärmeleistung	W
Φ_{erf}	Auslegeleistung des Heizkörpers	W
Φ_L	bezogene Wärmeleistung des HK's je m Baulänge	W/m
$\Phi_{RH,i}$	Aufheizreserve nach DIN pr EN 12 831	W
$\Delta\Phi_{RH,i}$	Aufheizreserve, durch Betriebsheizfläche erreichbar	W
Φ_S	Norm-Wärmeleistung	W
α_i	Wärmeübergangskoeffizient	W/(m²K)
ϑ_a	Außentemperatur	°C
ϑ_i	Norm-Innentemperatur	°C
$\vartheta_{i'}$	Temperatur in unbeheizten Räumen	°C
$\vartheta_{i,A}$	Auslegungs-Innentemperatur	°C
ΔT_1	Vorlaufübertemperatur	K
ΔT_2	Rücklaufübertemperatur	K
ΔT	Wasserübertemperatur	K
ΔT_{1S}	Norm-Vorlaufübertemperatur	K
ΔT_{2S}	Norm-Rücklaufübertemperatur	K
ΔT_H	Übertemperatur der Heizfläche	K
ΔT_U	Untertemperatur der kalten Umfassungsfläche	K
φ	Einstrahlzahl	–

t_r	reference air temperature	°C
t_m	mean water temperature	°C
U_{Fe}	U-value of window (formerly k_{Fe})	W/(m²K)
U_U	U-value of enclosing surface	W/(m²K)
σ_{Ausl}	difference between inlet and outlet water temperatures	K
Φ	thermal output	W
Φ_{erf}	design thermal output of heating appliance	W
Φ_L	thermal output per unit length of heating appliance	W/m
$\Phi_{RH,i}$	heating-up reserve as per DIN pr EN 12 831	W
$\Delta\Phi_{RH,i}$	heating-up reserve, achievable through normal-duty heating surface	W
Φ_S	standard thermal output	W
α_i	heat transfer coefficient	W/(m²K)
ϑ_a	outdoor temperature	°C
ϑ_i	standard indoor temperature	°C
$\vartheta_{i'}$	temperature in unheated rooms	°C
$\vartheta_{i,A}$	design indoor temperature	°C
ΔT_1	inlet water excess temperature	K
ΔT_2	outlet water excess temperature	K
ΔT	water excess temperature	K
ΔT_{1S}	standard inlet water excess temperature	K
ΔT_{2S}	standard outlet water excess temperature	K
ΔT_H	Excess temperature of heating surface	K
ΔT_U	Under temperature of cold enclosing surface	K
φ	radiation coefficient	–

Begriffe

Freie Raumheizflächen

Freie Raumheizflächen sind frei vor, über oder unter einer Umfassungsfläche des zu beheizenden Raumes angebracht und besitzen, abgesehen von der Befestigung, keinen Kontakt zu der Umfassungsfläche. Beispiele hierfür sind Raumheizkörper und Deckenstrahlplatten.

Raumheizkörper

Raumheizkörper sind freie Raumheizflächen, die überwiegend vor einer seitlichen Umfassungsfläche, gelegentlich in einem Bodenschacht (als Unterflur-

Terms and definitions

Free heating surfaces

Free heating surfaces are installed in front of, above, or below, an enclosing surface of the room to be heated without being in contact with that enclosing surface except by means of the fixtures. Examples are heating appliances and ceiling-mounted radiant panels.

Heating appliances

Heating appliances are free heating surfaces which are mostly installed in front of a lateral enclosing surface, occasionally in a shaft in the floor (as underfloor konvektor) oder frei im Raum (als Raumtrenner o. ä.), aber vorteilhaft immer im unteren Raumbereich angeordnet sind, kurz auch Heizkörper.

Isotherme Umgebung

Alle Umfassungsflächen eines Raumes und die Luft haben überall die gleiche Auslegungs-Innentemperatur (siehe Abschnitt 4.2.2).

„Kalte" Umfassungsflächen

Umfassungsflächen von Räumen, die kälter sind als eine Fläche mit Auslegungs-Innentemperatur. Für die Auslegung (Abschnitt 6) werden nur „kalte" Umfassungsflächen herangezogen, deren Oberflächentemperaturen 4 K kälter sind als die Auslegungs-Innentemperatur und eine Mindestgröße von 0,5 m² (Rohbaumaß) überschreiten.

Funktionen

Eigenschaften einer Anlage, die eine Wirkung im Sinne der Anforderung haben.

Kritische Fugendurchlässigkeit

Die Fugendurchlässigkeit wird nach DIN EN 12 207 beschrieben durch eine Referenzluftdurchlässigkeit für 1 m Fugenlänge bei einem Prüfdruck von 100 Pa. Als kritischer Wert im Sinne dieser Richtlinie wird die obere Grenze der Klasse 2 mit 6,75 m³/mh festgelegt, d. h. bei den Klassen 1 und 0 ist ein Behaglichkeitsdefizit vorauszusetzen.

Untertemperatur

Die Differenz zwischen einer mittleren Oberflächentemperatur und der Auslegungs-Innentemperatur.

Betriebsheizfläche

Die Raumheizfläche, die bei üblicher Heizung ständig in Betrieb ist.

Zusatzheizfläche

Die Raumheizfläche, die zusätzlich zur Betriebsheizfläche bei Aufheizfällen in Betrieb genommen wird.

Norm-Wasserstrom

Der Wasserstrom unter Norm-Prüfbedingungen

Heizkörpermodell

Heizkörper einer bestimmten Höhe, Länge und Tiefe innerhalb einer Modellreihe (gemäß DIN EN 442: Heizkörper ähnlicher Bauart, deren Querschnitt gleich bleibt, während Höhe oder Länge sich ändern oder bei denen nur ein charakteristisches Maß der trockenen Heizfläche einer systematischen Änderung

convectors), or free-standing in a room (functioning as partitions, etc.). In any case, however, heating appliances are conveniently arranged in the lower part of the room.

Isothermal environment

At any point in a room, all its enclosing surfaces and the air have the same design indoor temperature (see Section 4.2.2).

"Cold" enclosing surfaces

Those enclosing surfaces of a room which are colder than a surface at design indoor temperature. Only those "cold" enclosing surfaces are taken into account for designing (see Section 6), whose surface temperature lies 4 K below the design indoor temperature and whose area is at least 0,5 m² (dimensions in unfinished state).

Functions

Those characteristics of a system that have a bearing on its compliance with requirements.

Critical joint permeability

As per DIN EN 12207, joint permeability is described in terms of a reference air permeability for a joint length of 1 m and a test pressure of 100 Pa. For the purposes of this guideline, the critical value has been set to equal the upper limit of class 2, i. e. 6,75 m³/mh, which means that a deficit in comfort must be assumed for classes 0 and 1.

Under temperature

The difference between a mean surface temperature and the design indoor temperature.

Operating heating area

Heating area which is permanently in operation during normal heating.

Additional heating surface

Heating surface which, for heating up, is used in addition to the normal-duty heating surface.

Standard water flow rate

Water flow rate under standardized test conditions

Heating-appliance model

Heating appliance within a series of models, featuring a specific height, length and width. (According to DIN EN 442, a series of models comprises heating appliances of similar design, whose cross section remains the same whereas height and length may change, or where only one characteristic dimension unterliegt).

of the dry heating-surface area is subject to systematic variation.)

4 Definition und Zusammenstellung der Anforderungen

4.1 Pflichtenheft

Im Pflichtenheft werden die Anforderungen des Auftraggebers an die Heizanlage aufgelistet. Insbesondere müssen Anforderungen, die von den Empfehlungen einschlägiger technischer Regeln abweichen, aufgenommen werden. Mit dem Pflichtenheft können später die Vollständigkeit und Erfüllung der Funktionen der Heizanlage überprüft und die Planungsvarianten (Angebote) verglichen werden.

Das Pflichtenheft ist Bestandteil des Raumbuches und muss mindestens folgende Angaben enthalten:

Auslegungsvorgaben:

- Auslegungs-Innentemperatur $\vartheta_{i,A}$ nach Abschnitt 4.2.2
- Anforderungszone nach Abschnitt 4.2.4
- Anforderungsstufe nach Abschnitt 4.2.5
- Aufheizreserve nach Abschnitt 4.2.6 und 5.2.9

Weitere Vorgaben:

- Zusatznutzen nach Abschnitt 4.2.7
- Maximale Aufwandszahl $e_{1,\max}$ nach VDI 2067 Blatt 20 (optional)

Im Anhang A ist ein Beispiel-Pflichtenheft vorgegeben.

4.2 Auslegungsvorgaben

4.2.1 Norm-Innentemperatur

Die Norm-Innentemperatur ϑ_i eines Raumes ist eine „empfundene Temperatur“ (operative Temperatur), die sowohl die Lufttemperatur als auch die mittlere Umfassungsflächentemperatur (richtungsunabhängig) berücksichtigt (DIN pr EN 12 831, DIN 4701-1). Sie ist eine rechnerische Größe (DIN 4701-3).

4.2.2 Auslegungs-Innentemperatur

Die Auslegungs-Innentemperatur $\vartheta_{i,A}$ ist die Norm-Innentemperatur, die für den Auslegungsfall in ihrem Wert festgelegt wird. Vorschläge über ihren Wert für Räume unterschiedlicher Nutzung enthält DIN pr EN 12 831 bzw. DIN 4701-2. Diese können jedoch nach Vorgabe durch den Auftraggeber davon abweichen (Pflichtenheft).

4 Definition and compilation of requirements

4.1 Target specification

The target specification lists the orderer's requirements to be met by the heating system. It is of particular importance that those requirements which deviate from recommendations given in the relevant technical rules be included. Later on, the target specification will allow to check the heating system for completeness and functional compliance, and to compare planning variants (tenders).

The target specification for the heating system is part of the specification of rooms. It shall at least contain the following information:

Design specifications:

- Design indoor temperature, $\vartheta_{i,A}$, as per Section 4.2.2
- Requirements zone as per Section 4.2.4
- Class of requirements as per Section 4.2.5
- Heating-up reserve as per Sections 4.2.6 and 5.2.9

Further specifications:

- Additional use as per Section 4.2.7
- Maximum effort number, $e_{1,\max}$ as per VDI 2067 Part 20 (optional)

Annex A shows an example of a target specification.

4.2 Design specifications

4.2.1 Standard indoor temperature

The standard indoor temperature, ϑ_i, of a room is a "subjective temperature" (operative temperature) taking into account both the air temperature and the mean temperature of the enclosing surfaces (non-directional) (DIN pr EN 12 831, DIN 4701-1). It is a calculated quantity (DIN 4701-3).

4.2.2 Design indoor temperature

The design indoor temperature, $\vartheta_{i,A}$, is the standard indoor temperature specified for the particular room for which the heating system is to be designed. Recommended values for rooms with different types of use are given in DIN pr EN 12831 and DIN 4701-2. Different values may, however, be used if so specified by the orderer (target specification).

4.2.3 Behaglichkeitsdefizite[3)]

Behaglichkeitsdefizite werden hervorgerufen durch:

- „Kalte" Umfassungsflächen
- Luftströmungen in Folge der Fugendurchlässigkeit (kritische Fugendurchlässigkeit) oder an Zuluftdurchlässen (auch für Verbrennungsluft) in den Raumumfassungsflächen.

Diese Defizite werden aufgefasst als Unterschiede gegenüber einer von Luftströmungen ungestörten isothermen Umgebung mit Auslegungs-Innentemperatur. Sie können daher definitionsgemäß im Raum nur außerhalb der Anforderungszone auftreten. Als Behaglichkeitsdefizite „kalter" Umfassungsflächen treten auf Grund der Untertemperatur das Strahlungsdefizit und die Fallluftströmung auf.

[3)] Zum Zwecke der Auslegung freier Raumheizflächen eingeführte Definition

4.2.3 Deficits in comfort[3)]

Deficits in comfort are caused by:

- "cold" enclosing surfaces, and
- air flows due to joint permeability (critical joint permeability) or near air inlets (also for combustion air) in the surfaces enclosing the room.

These deficits are considered as differences with respect to an isothermal environment at design indoor temperature, which is undisturbed by air flows. Therefore, by definition, such deficits can only occur outside the requirements zone in a room. Radiation deficit and downdraft are deficits in comfort which are due to the under temperature of "cold" enclosing surfaces.

[3)] This definition has been introduced for the purposes of designing free heating surfaces.

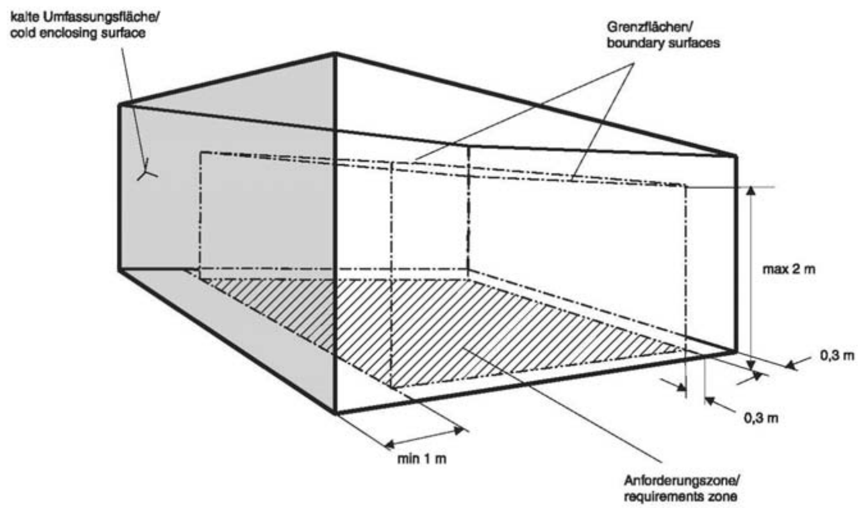


Bild 1. Grenzflächen der max. Anforderungszone
(Beispiel für einen Raum mit einer „kalten" Umfassungsfläche)

Fig. 1. Boundary surfaces of the maximum requirements zone
(example of a room with one "cold" enclosing surface)

4.2.4 Anforderungszone

Die Anforderungszone im Sinne dieser VDI-Richtlinie definiert den Teil eines beheizten Raumes, in dem die gewünschten Anforderungen im Hinblick auf die Behaglichkeit nach Abschnitt 4.2.5 und damit auch die weitgefassten nach DIN EN ISO 7730 erfüllt sind. Ihre Ausdehnung und Lage wird von der Größe und Anordnung der freien Raumheizfläche, also ihrer Auslegung, bestimmt. Die Vorgabe der Anforderungszone (durch den Auftraggeber) dient daher der Auswahl von freien Raumheizflächen und ihrer Anordnung in Verbindung mit der Festlegung der Anforderungsstufe.

Die durch den Auftraggeber vorgegebene Anforderungszone wird nur durch horizontale und vertikale Flächen begrenzt, also durch Abstände von den Umfassungsflächen bzw. durch Raumhöhen. Sie ist in der Regel kleiner als die maximale Anforderungszone (Bild 1). Der Mindestabstand von der „kalten“ Umfassungsfläche beträgt 1 m, der Mindestabstand zu allen anderen senkrechten Umfassungsflächen beträgt 0,3 m; die Höhe der Anforderungszone ist maximal 2 m. Räume mit mehreren Fußbodenebenen (versetzte Bauweise, mehrere Geschosse) sind gesondert zu betrachten und bedingen mehrere Anforderungszonen.

Die tatsächlich herstellbare Anforderungszone ist durch gekrümmte Flächen mit in der Höhe variablen Abständen zu den „kalten“ Umfassungsflächen hin begrenzt.

Die Grenzfläche der mit verschiedenen Heizsystemen und unterschiedlicher Heizflächen-Anordnungen herstellbaren Anforderungszone kann für gleiche Wärmestromdichten an einem bestimmten Körperoberflächenelement (immer parallel zur „kalten“ Umfassungsfläche) für vorgegebene Behaglichkeitsbedingungen berechnet werden (siehe Anhang D). Dabei wird es als ausreichend angesehen, bei vertikalen „kalten“ Umfassungsflächen lediglich einen Grenzwert in einer Raumhöhe von 0,75 m zu bestimmen (die Unterschiede in der Horizontalen und in der Vertikalen werden nicht weiter verfolgt). Ein Beispiel für die Grenzlinie der Anforderungszone (mit Anforderungsstufe 3) auf der für die Betrachtung herangezogenen Horizontalebene zeigt die Darstellung in Bild D2.

4.2.5 Anforderungsstufe

Für die gewählte Anforderungszone lässt sich die gewünschte Anforderungsstufe durch unterschiedlich umfangreiche Beseitigung der Behaglichkeitsdefizite festlegen. Dabei sind drei Anforderungsstufen ausreichend.

4.2.4 Requirements zone

For the purposes of this VDI-guideline, the requirements zone defines that part of a heated room where the desired comfort requirements given in Section 4.2.5, and thus also the less strict specifications of DIN EN ISO 7730, are met. The area over which it extends, and its location are determined by the dimensions and the arrangement, i.e. by the design, of the free heating surface in the room. The (target) specification for the requirements zone in combination with the specified class of requirements therefore serves as a basis for the selection of free heating surfaces and their arrangement.

The requirements zone specified by the orderer is only confined by horizontal and vertical surfaces, i.e. in terms of distances from the enclosing surfaces, and room heights. It is usually smaller than the maximum requirements zone (see Figure 1). The minimum distance from the “cold” enclosing surface is 1 m, the minimum distance to any other vertical enclosing surface is 0,3 m. The maximum height of the requirements zone is 2 m. Rooms with several floor planes (split levels, several storeys) require special consideration, and several requirements zones.

The effectively achievable requirements zone is confined by curved surfaces whose distances to the “cold” enclosing surfaces vary with height.

The boundary surfaces of the requirements zones that can be achieved with the same heat flow density at a specific body surface element (always parallel to the “cold” enclosing surface), using different heating systems and heating-surface arrangements, can be calculated for specified comfort criteria (see Annex D). It is deemed sufficient to determine just one limit at a room height of 0,75 m for vertical “cold” enclosing surfaces. (The differences in the horizontal and vertical planes are not investigated in further detail.) Figure D2 shows the boundary line of the requirements zone (class 3 requirements) on the horizontal plane that forms the basis of this consideration.

4.2.5 Class of requirements

The class of requirements desired for the selected requirements zone can be determined by compensating deficits in comfort to a varying degree. Three classes of requirements are sufficient.

Stufe 3: Vollständige Beseitigung der Behaglichkeitsdefizite[4)]

Die dritte Stufe liegt vor, wenn durch Anordnung, Abmessung und Übertemperatur der freien Raumheizfläche Behaglichkeitsdefizite (nach Abschnitt 4.2.3) auf Grund baulicher oder betrieblicher Bedingungen vollständig beseitigt sind. Dieses gilt insbesondere als erreicht, wenn

1. die Heizfläche auf Grund ihrer Länge und Anordnung eine Fallluftströmung abfängt (Heizkörperlänge ≈ Fensterbreite)
2. ein Strahlungsdefizit in der Anforderungszone nicht auftritt
3. die Raumheizfläche unmittelbar vor derselben Ebene (parallel) wie die „kalte" Umfassungsfläche angeordnet ist
4. die Ansichtsfläche und die Übertemperatur der Raumheizfläche das Strahlungsdefizit (siehe Abschnitt 5.1.2) der Umfassungsfläche ausgleicht
5. die Raumheizfläche die Normheizlast deckt (DIN pr EN 12 831 bzw. DIN 4701)
6. die vereinbarte Aufheizreserve berücksichtigt ist

Die dritte Stufe liegt ebenfalls vor, wenn baulich keine „kalten" Umfassungsflächen vorliegen sowie keine störenden Luftströmungen die vorgegebene Anforderungszone erreichen und durch anlagentechnische Maßnahmen die oben angegebenen Bedingungen 5.) und 6.) erfüllt sind.

Stufe 2: Teilweise Beseitigung der Behaglichkeitsdefizite

Sie ist dann erreicht, wenn gegenüber Stufe 3 lediglich ein Strahlungsausgleich vorgesehen ist (Anordnung einer freien Raumheizfläche an einer „kalten" Umfassungsfläche oder unter einem Fenster in nicht ausreichender Länge, oder neben Fenster/Tür). Die Bedingungen für Übertemperatur, Normheizlast sowie Aufheizreserve sind unter Stufe 3 angegeben.

Stufe 1: Deckung der Normheizlast ohne Beseitigung von Behaglichkeits-defiziten[5)]

Diese gilt dann als erfüllt, wenn die freie Raumheizfläche lediglich die Normheizlast deckt (DIN pr EN 12 831 bzw. DIN 4701). Hier ist die Anordnung, Art und Größe der Raumheizfläche (Ansichtsfläche) frei wählbar, bei der Wahl der Übertemperatur sind die Grenzwerte nach Abschnitt 5.3 zu beachten. Eine

[4)] im Sinne dieser Richtlinie

[5)] Bei Anforderungsstufe 1 entspricht die Anforderungszone automatisch der gesamten Raumfläche

Class 3: Complete compensation of deficits in comfort[4)]

Class 3 has been achieved when the arrangement, dimensions and excess temperature of the free heating surface are such that deficits in comfort (as per Section 4.2.3) arising from structural or operational conditions are compensated completely. This is particularly assumed to be fulfilled when

1. the length and arrangement of the heating surface are such that it intercepts any downdraft (length of heating appliance approximately equals the length of the window)
2. there is no radiation deficit within the requirements zone
3. the heating surface is arranged directly in front of (and parallel to) the plane of the "cold" enclosing surface
4. the visible-surface area and the excess temperature of the heating surface compensate the radiation deficit (see Section 5.1.2.) of the enclosing surface
5. the heating surface covers the design heating load (DIN pr EN 12831 or DIN 4701)
6. the agreed heating-up reserve has been observed

Class 3 has been achieved as well when there are not "cold" enclosing surfaces and interfering air flows remaining outside the specified requirements zone and if the above mentioned conditions 5.) respectively 6.) are fulfilled by measures of systems engineering.

Class 2: Partial compensation of deficits in comfort

This class is achieved when, in contrast to class 3, provision is only made for radiation deficits to be compensated (by arranging a free heating surface next to a "cold" enclosing surface, or a free heating surface with insufficient length under a window, or a free heating surface to the side of a window/door). The criteria for excess temperature, design heating load and heating-up reserve are as given for class 3.

Class 1: Provision of design heating load without compensation of deficits in comfort[5)]

Class 1 is deemed to be achieved when the free heating surface merely covers the design heating load (DIN pr EN 12831 or DIN 4701). Arrangement, type and dimensions of the heating surface (visible surface) can be chosen arbitrarily, limits for the excess temperature as per Section 5.3 shall be observed. A

[4)] as defined in this guideline

[5)] The requirements zone for class 1 automatically equals the entire area of the room.

Aufheizreserve ist nicht oder nur zum Teil berücksichtigt, Behaglichkeitsdefizite (nach Abschnitt 4.2.3) können nicht oder nur zum Teil ausgeglichen werden.

4.2.6 Aufheizreserve

Die Aufheizreserve wird definiert als Leistungsreserve der Raumheizfläche zum Zweck der Aufheizung eines Raumes aus dem Absenk-Heizbetrieb heraus. Anhaltswerte für den erforderlichen Leistungsbetrag $\Phi_{RH,j}$ liefert DIN pr EN 12 831.

Eine Aufheizreserve kann durch den Einbau einer zusätzlichen, im Normalbetrieb abgestellten Raumheizfläche bereitgehalten werden; sie ist prinzipiell unbegrenzt. Eine derartige Reserve ist im Pflichtenheft vorzugeben, insbesondere dann, wenn eine begrenzte Aufheizzeit möglich sein soll.

Eine gewisse Aufheizreserve kann vorliegen auf Grund der Möglichkeit, die Vorlauftemperatur und/oder den Wasserstrom über den Auslegungswert hinaus anzuheben. Diese Reserve ist begrenzt durch Auslegungs- und Anlagenbedingungen. Um sie nutzen zu können, müssen entsprechende Schalt- und Steuereinrichtungen vorgesehen sein.

4.2.7 Zusatznutzen

In welcher Weise die auszulegende Raumheizfläche über die Heizfunktion hinaus als Handtuchhalter, Garderobe, Raumteiler oder anders genutzt wird, ist vom Auftraggeber festzulegen. Gegebenenfalls sind aus Gründen der Anordnung und Abmessungen Einschränkungen bei den Anforderungsstufen hinzunehmen.

5 Grundlagen für die Auslegung

5.1 Behaglichkeitsdefizite

5.1.1 Untertemperatur „kalter" Umfassungsflächen

Die für das Strahlungsdefizit bei einer „kalten" Umfassungsfläche maßgebliche Untertemperatur berechnet sich nach Gleichung (1):

$$\Delta T_U = \frac{U_U}{\alpha_i}(\vartheta_{i,A} - \vartheta_a) \qquad (1)$$

Bei waagrechten bzw. senkrechten Umfassungsflächen sind die Wärmeübergangswiderstände $1/\alpha_i$ nach Tabelle 1 einzusetzen.

heating-up reserve is not, or only partially, provided for. Deficits in comfort (as per Section 4.2.3) cannot, or only partially, be compensated.

4.2.6 Heating-up reserve

The heating-up reserve is, by definition, the power reserve of the heating surface, which is available for heating up the room after economy operation of the heating system. Reference values of the required capacity, $\Phi_{RH,j}$, are given in DIN pr EN 12 831.

A heating-up reserve can be provided by installing an additional heating surface that is not used during normal operation. In principle, there is no limitation. Such a reserve shall be specified in the target specification, particularly when heating up is to be completed within a limited period of time.

As it is possible to raise the inlet water temperature and/or the water flow rate beyond the design value(s), there may be a certain heating-up reserve which is limited by the design and system conditions. Appropriate switchgear and controlgear must be provided in order to make this reserve available.

4.2.7 Additional use

The orderer shall specify any use of the heating surface to be designed, which goes beyond heating, for instance, if it also serves to hang towels or clothes, to partition a room, etc. If necessary, limitations in the class of requirements must be accepted for reasons of arrangement and dimensions.

5 Fundamentals of designing

5.1 Deficits in comfort

5.1.1 Under temperature of "cold" enclosing surfaces

The under temperature relevant to the radiation deficit caused by one "cold" enclosing surface is calculated as per Equation (1):

$$\Delta T_U = \frac{U_U}{\alpha_i}(\vartheta_{i,A} - \vartheta_a) \qquad (1)$$

Assume heat transfer resistances, $1/\alpha_i$, as given in Table 1 for horizontal and vertical enclosing surfaces.

Tabelle 1. Wärmeübergangswiderstände $1/\alpha_i$ nach DIN 4108-4

Bauteil	$1/\alpha_i$ in $(m^2K)/W$
Außenwand/Außenfenster	0,13
Wohnungstrennwand	0,13
An Erdreich grenzende Wand	0,13
Decke	0,13
Kellerdecke	0,17

Table 1. Heat transfer resistances, $1/\alpha_i$, as per DIN 4108-4

Building component	$1/\alpha_i$ in $(m^2K)/W$
Exterior wall/window	0,13
Party wall	0,13
Wall in contact with ground	0,13
Ceiling	0,13
Cellar ceiling	0,17

Für die Umfassungsfläche können Anhaltswerte für die sich einstellende Untertemperatur an der Innenoberfläche in Abhängigkeit der Temperaturdifferenz ($\vartheta_{i,A}$ - ϑ_a) und des U-Wertes der Umfassungsfläche Bild C1 (Anhang C) entnommen werden.

Refer to Figure C1 (Annex C) for reference values of the under temperature on the inside of the enclosing surface as a function of the temperature difference ($\vartheta_{i,A}$ - ϑ_a) and the U-value of the enclosing surface.

5.1.2 Strahlungsdefizit durch „kalte" Umfassungsflächen

Das Strahlungsdefizit durch „kalte" Umfassungsflächen wird ausreichend genau durch einen linearen Ansatz mit $A_U \cdot \Delta T_U$ beschrieben. Für seinen Ausgleich durch Zustrahlung einer freien Raumheizfläche gilt mit einem analogen Ansatz:

$$\Delta T_H \geq \frac{A_U \cdot \Delta T_U}{\sum L_{HK} \cdot H_{HK}} \tag{2}$$

Bei mehreren Flächen j und k (in einer Ebene) gilt entsprechend Gleichung (3):

$$\Delta T_H \geq \frac{\sum A_{Uj} \cdot \Delta T_{Uj}}{\sum L_{HK,\,k} \cdot H_{HK,\,k}} \tag{3}$$

5.1.2 Radiation deficit due to "cold" enclosing surfaces

The radiation deficit due to "cold" enclosing surfaces is described to sufficient accuracy by a linear function of $A_U \cdot \Delta T_U$. Its compensation by means of radiation from a free heating surface is described by an analogous approach:

$$\Delta T_H \geq \frac{A_U \cdot \Delta T_U}{\sum L_{HK} \cdot H_{HK}} \tag{2}$$

If several surfaces, j and k (in one plane), are to be considered, use Equation (3):

$$\Delta T_H \geq \frac{\sum A_{Uj} \cdot \Delta T_{Uj}}{\sum L_{HK,\,k} \cdot H_{HK,\,k}} \tag{3}$$

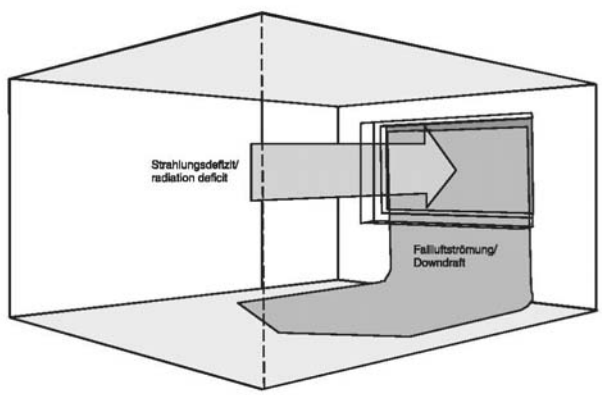


Bild 2. Strahlungsdefizit und Fallluftströmung an „kalten" Flächen

Fig. 2. Radiation deficit and downdraft near "cold" enclosing surfaces

5.1.3 Fallluftströmung an „kalten" Umfassungsflächen

Die sich an einer „kalten" Umfassungsfläche abkühlende Luft führt zu einer Fallluftströmung mit Geschwindigkeiten von bis zu 0,3 m/s am Fuß der Fläche und einem breitenbezogenen Luftstrom von z. B. 45 m^3/hm [1] (Beispiel für ein Fenster: 2 m hoch, U_{Fe}=1,1 W/m^2K, Fensteruntertemperatur 4,6 K).

5.1.4 Luftströmung durch Zuluft

Luftströmungen durch Zuluft entstehen an Undichtigkeiten (Infiltration) und Zuluftdurchlässen (Nachströmöffnungen, z. B. für raumluftabhängige Wärmeerzeuger) in der Umfassungsaußenfläche.

Behaglichkeitsdefizite durch Zuluft an Öffnungen zur freien Lüftung müssen durch entsprechende Anordnung von Heizflächen ausgeglichen werden. Hierbei sind DIN 1946-6, DIN 18 017-1/-3, die TRGI und die Herstellerangaben zu den Nachströmöffnungen zu beachten.

5.2 Größen für die Auslegung der freien Raumheizflächen

5.2.1 Wasserübertemperatur

Die Wasserübertemperatur ΔT wird bestimmt aus der Differenz von mittlerer Wassertemperatur t_m und Auslegungs-Innentemperatur $\vartheta_{i,A}$ nach Gleichung (4):

$$\Delta T = t_m - \vartheta_{i,A} \quad (4)$$

Sie ist abhängig von der Heizflächenart und etwa gleich der Heizflächenübertemperatur ΔT_H. Bei nicht direkt wasserdurchströmten Frontflächen ist die Differenz der Oberflächentemperatur zu berücksichtigen (Herstellerangabe). Für die Auslegung der Heizfläche wird der Wert aus Gleichung (2) bzw. (3) angesetzt.

5.2.2 Auslegungsspreizung

Die Auslegungsspreizung σ_{Ausl} ist die Differenz zwischen Vor- und Rücklauftemperatur nach Gleichung (5):

$$\sigma_{Ausl} = t_1 - t_2 \quad (5)$$

5.2.3 Vorlaufübertemperatur

Die Vorlaufübertemperatur ΔT_1 wird als Differenz aus Vorlauftemperatur t_1 und der Auslegungs-Innentemperatur $\vartheta_{i,A}$ nach Gleichung (6) berechnet.

$$\Delta T = t_1 - \vartheta_{i,A} \quad (6)$$

5.1.3 Downdraft near "cold" enclosing surfaces

The cooling of the air near a "cold" enclosing surface entails a downdraft, with the flow velocity at the bottom of the surface reaching up to 0,3 m/s, and the air flow per unit width of surface being, e. g., 45 m^3/hm [1] (example: two-metre-high window with U_{Fe}=1,1 W/m^2K and an under temperature of 4,6 K).

5.1.4 Air flows caused by air supply

Air flows caused by air supply are found near leaks (infiltration) and air inlets (air supply openings such as for heat generators consuming indoor air) in the enclosing surface.

Deficits in comfort caused by air supply through openings for free ventilation must be compensated by means of a suitable arrangement of heating surfaces. Observe DIN 1946-6, DIN 18017-1 and -3, TRGI, and the manufacturer's specifications concerning the air supply openings.

5.2 Quantities used for designing the free heating surfaces

5.2.1 Water excess temperature

The water excess temperature, ΔT, is determined from the difference of the mean water temperature, t_m, and the design indoor temperature, $\vartheta_{i,A}$, as per Equation (4):

$$\Delta T = t_m - \vartheta_{i,A} \quad (4)$$

It depends on the type of heating surface and approximately equals the excess temperature of the heating surface, ΔT_H. Where the front face does not itself carry the water flow, the difference of the surface temperature must be taken into account (manufacturer's specification). The value obtained from Equation (2) or Equation (3) is used for designing the heating surface.

5.2.2 Design difference between inlet and outlet water temperatures

The difference between inlet and outlet water temperatures, σ_{Ausl}, is given in Equation (5):

$$\sigma_{Ausl} = t_1 - t_2 \quad (5)$$

5.2.3 Inlet water excess temperature

The inlet water excess temperature, ΔT_1, is calculated as the difference between the inlet water temperature, t_1, and the design indoor temperature, $\vartheta_{i,A}$, using Equation (6)

$$\Delta T = t_1 - \vartheta_{i,A} \quad (6)$$

5.2.4 Normheizlast

Als Normheizlast $\dot{Q}_N$ eines Raumes wird die Wärmeleistung bezeichnet, die dem Raum unter Norm-Witterungsbedingungen zugeführt werden muss, damit sich die geforderten thermischen Norm-Innenraumbedingungen einstellen (Norm-Innentemperatur, Auslegungs-Innentemperatur).

Die Normheizlast wird berechnet nach DIN pr EN 12 831 bzw. DIN 4701.

5.2.5 Wärmeleistung

Die Wärmeleistung Φ ist die zeitbezogene Wärmeabgabe der Raumheizfläche im Beharrungszustand. Sie ist entweder der Vorlaufübertemperatur ΔT_1 und dem Wasserstrom q_m oder ΔT_1 und der Rücklaufübertemperatur ΔT_2 zugeordnet (siehe 5.2.11). Die erforderliche Auslegungsleistung Φ_{erf} muss mindestens so groß sein, wie die Normheizlast $\dot{Q}_N$.

5.2.6 Norm-Wärmeleistung der Raumheizkörper

Die Norm-Wärmeleistung Φ_S bzw. Φ_{LS} (längenbezogen) für Raumheizkörper ist nach DIN EN 442-2 die unter folgenden Bedingungen abgegebene Wärmeleistung:

Vorlauftemperatur	t_1 = 75 °C
Rücklauftemperatur	t_2 = 65 °C
Bezugs-Lufttemperatur	t_r = 20 °C
Bezugs-Luftdruck	p_0 = 101,3 kPa

Sie ist eine Kenngröße für den tatsächlich eingebauten Raumheizkörper (nur in Stufen erhältlich entsprechend Heizkörperkatalog).

5.2.7 Einfluss der Anschlussart auf die Norm-Wärmeleistung der Raumheizkörper

Die Norm-Wärmeleistung, bestimmt nach DIN EN 442, gilt bei Heizkörpern ohne Wasserzwangsführung für oberen Vorlaufanschluss und unteren Rücklaufanschluss sowohl bei gleichseitiger als auch bei wechselseitiger Anordnung der Anschlüsse. Bei anderen, vom Hersteller vorgegebenen Anschlussarten wird die Norm-Wärmeleistung unter diesen Bedingungen ermittelt. Bei allen, von den vorgenannten abweichenden Anschlussarten oder bei Anschluss mit Spezialventilen können je nach Ausführung erhebliche Leistungsminderungen auftreten. Sie entstehen durch Mischvorgänge auf der Wasserseite des Heizkörpers, die vereinfacht durch einen Beimischwert b erfasst sind (siehe Erläuterungen und

5.2.4 Design heating load

The design heating load, $\dot{Q}_N$, is the thermal output to be supplied to a room under standard meteorological conditions to achieve the required standard thermal indoor conditions (standard indoor temperature, design indoor temperature).

The design heating load is calculated in accordance with DIN pr EN 12 831 or DIN 4701.

5.2.5 Thermal output

The thermal output, Φ, is the amount of heat per unit time supplied by the heating surface in steady-state operation. It is either associated with the inlet water excess temperature, ΔT_1, and the water flow rate, q_m, or with ΔT_1 and the outlet water excess temperature, ΔT_2 (see Section 5.2.11). The required design thermal output, Φ_{erf}, must at least equal the design heating load, $\dot{Q}_N$.

5.2.6 Standard thermal output of the heating appliances

As per DIN EN 442-2, the standard thermal output, Φ_S, or Φ_{LS} (referred to length) of heating appliances is the thermal output under the following conditions:

Inlet water temperature	t_1 = 75 °C
Outlet water temperature	t_2 = 65 °C
Reference air temperature	t_r = 20 °C
Reference air pressure	p_0 = 101,3 kPa

The standard thermal output is a characteristic of the heating appliance actually installed in the room (which is only available in units as per the heating-appliance catalogue).

5.2.7 Influence of the type of connection on the standard thermal output of heating appliances

The standard thermal output of a heating appliance without forced water flow, as determined in accordance with DIN EN 442, is only valid for inlet at the top and outlet at the bottom, regardless of whether both connections are arranged on the same side or on opposite sides. Where the manufacturer specifies other types of connections, the standard thermal output is determined for those conditions. Depending on the installation, considerable losses in thermal output can occur with any type of connection differing from those mentioned above, or when special valves are fitted. They are the consequence of mixing processes on the water side of the heating appliance, which are taken into account in a simplified way by using the

Anhaltswerte im Anhang B).

5.2.8 Einfluss von Beschichtung und Einbau

Alle Leistungsangaben beziehen sich auf Raumheizkörper mit nichtmetallischen Beschichtungen (Farb- oder Lackanstrich). Metallische Beschichtungen (z. B. Metallbronzen) können die Wärmeabgabe bei Raumheizkörpern mit hohem Strahlungsanteil beträchtlich vermindern (bis zu 50 %). Bei Einbau von Radiatoren (Gliederheizkörpern, Plattenheizkörpern und ähnlichem) in Nischen oder bei Anordnung von oberen Abdeckplatten ist je nach Heizkörpertyp mit Leistungsminderungen gemäß Bild B2–B4 zu rechnen.

5.2.9 Aufheizreserve

Die Aufheizreserve $\Phi_{RH,j}$ muss im Pflichtenheft vorgegeben sein. Anhaltswerte hierfür liefert DIN pr EN 12 831. Die durch Auslegungs- und Anlagenbedingungen (Anhebung der Vorlauftemperatur und/oder des Wasserstroms) gegebene Aufheizreserve $\Delta\Phi_{RH,j}$ (der Betriebsheizfläche) errechnet sich aus der Maximalleistung Φ_{max} abzüglich der Auslegungsleistung Φ_{erf} nach Gleichung (7):

$$\Delta\Phi_{RH,j} = \Phi_{max} - \Phi_{erf} \tag{7}$$

Eine durch Zusatzheizfläche (Leistung Φ_{zus}) hergestellte Aufheizreserve liefert insgesamt (zusammen mit der „Betriebsheizfläche"):

$$\Phi_{RH,j} = (\Phi_{max} + \Phi_{zus}) - \Phi_{erf} = \Delta\Phi_{RH,j} + \Phi_{zus} \tag{8}$$

Die Gesamtaufheizreserve $\Phi_{RH,j}$ muss gleich oder größer sein als die mit der Betriebsheizfläche bereits erreichbare Aufheizreserve $\Delta\Phi_{RH,j}$.

5.2.10 Wasserstrom

Der Wasserstrom q_m ist der Wasser-Massenstrom durch die jeweilige Raumheizfläche. Er soll bei Raumheizkörpern aus Gründen einer günstigen Regelbarkeit nicht größer sein als der Wasserstrom bei einer Spreizung $\sigma = \Delta T_1/3$ oder $\sigma = 2/5\Delta T_H$. Der Gesamtwasserstrom der Anlage ist die Summe der Einzel-Wasserströme der Raumheizflächen.

5.2.11 Auslegungsdiagramm

Im Auslegungsdiagramm eines Raumheizkörpers (Bild C3 bis C6, Anhang C) ist der Zusammenhang zwischen Vorlaufübertemperatur ΔT_1, Rücklaufübertemperatur ΔT_2, Verhältnis von Wärmeleistung zu Norm-Wärmeleistung Φ/Φ_S und Wasserstrom zu Norm-Wasserstrom q_m/q_{mS} dargestellt, siehe DIN 4703 T3. Die Kurvenschar des Auslegungsdia-

mixing coefficient, b (see explanatory information and reference values in Annex B).

5.2.8 Effects of coating and installation

Information on the thermal output refer to heating appliances with non-metallic coatings (paint or varnish). Metallic coatings (such as metallic bronze) can lead to significant reductions in the thermal output of heating appliances where the contribution of radiation is high (up to 50 %). Where radiators (sectional radiators, plate radiators and similar heating appliances) are installed in niches, or where cover plates are provided, expect reductions in thermal output depending on the type of heating appliance, as per Figures B2 through B4.

5.2.9 Heating-up reserve

The heating-up reserve, $\Phi_{RH,j}$, shall be specified in the target specification. Reference values for this quantity are given in DIN pr EN 12 831. The heating-up reserve (of the normal-duty heating surface) afforded by the design and system conditions (increase in inlet water temperature and/or water flow rate), $\Delta\Phi_{RH,j}$, is calculated from the maximum thermal output, Φ_{max}, minus the design thermal output, Φ_{erf}, as per Equation (7):

$$\Delta\Phi_{RH,j} = \Phi_{max} - \Phi_{erf} \tag{7}$$

With a heating-up reserve provided by an additional heating surface (thermal output Φ_{zus}), the total heating-up reserve (additional heating surface plus "normal-duty heating surface") is:

$$\Phi_{RH,j} = (\Phi_{max} + \Phi_{zus}) - \Phi_{erf} = \Delta\Phi_{RH,j} + \Phi_{zus} \tag{8}$$

The total heating-up reserve, $\Phi_{RH,j}$, must at least equal the heating-up reserve, $\Delta\Phi_{RH,j}$ afforded by the normal-duty heating surface alone.

5.2.10 Water flow rate

The water flow rate, q_m, is the mass per unit time of water flowing through the heating surface in question. For reasons of good controllability, it shall not be greater than the water flow rate for a difference $\sigma = \Delta T_1/3$, or $\sigma = 2/5\Delta T_H$, if possible. The total water flow rate of the system is the sum of the water flow rates through the individual heating surfaces.

5.2.11 Design diagram

The design diagram of a heating appliance (see Figures C3 through C6 in Annex C) illustrates the relation between the inlet and outlet water excess temperatures, ΔT_1 and ΔT_2, respectively, the ratios of thermal output over standard thermal output, Φ/Φ_S, and of water flow rate over standard water flow rate, q_m/q_{mS}, see DIN 4703-3. The set of curves in the degramms beschreibt das Verhalten eines Raumheizkörpers, dessen Kennlinie durch eine Potenzfunktion mit dem Exponenten n sowie dem von Bau- und Anschlussart abhängigen Beimischwert b (Algorithmen im Anhang B) vorliegt.

sign diagram describes the target of a heating appliance whose characteristic curve is an exponential function of a power of n and the mixing coefficient, b, which depends on the types of installation and connection (algorithms given in Annex B).

5.3 Grenzwerte

Maximale und minimale Vorlauftemperatur

Die Vorlauf-Auslegungstemperatur wird durch die Beschränkung der Wasserübertemperatur nach oben und unten begrenzt. Als untere Grenze wird aus psychologischen Überlegungen (der Heizkörper muss sich im Betrieb warm anfühlen, da sonst „keine Wärmelieferung" assoziiert wird) $t_{1,\min} = 45$ °C empfohlen. Als obere Grenze wird aus Gründen der Energieeinsparung und der Unfallsicherheit (Körperkontakt von Kindern) $t_{1,\max} = 60$ °C empfohlen. Für die Bereitstellung einer Aufheizreserve kann $t_{1,\max}$ kurzzeitig überschritten werden.

5.3 Limit values

Maximum and minimum inlet water temperatures

The maximum and minimum values of the design inlet water temperature are given by the upper and lower limits of the water excess temperature. For psychological reasons (a heating appliance must feel warm to the touch while operating, or no supply of heat is associated), a lower limit of $t_{1,\min} = 45$ °C is recommended. No more than $t_{1,\max} = 60$ °C are recommended for the upper limit in order to save energy and avoid accidents (children touching the heating appliance). Exceeding $t_{1,\max}$ for a short period is permissible for the purpose of providing the heating-up reserve.

6 Auslegung von Raumheizkörpern

Im Folgenden wird die Auslegung von Raumheizkörpern (mit Strahlungswirkung[6)]) beispielhaft für die Anforderungsstufe 3 beschrieben. Als behaglichkeitsstörende Fläche wird dabei exemplarisch allein das Fenster betrachtet. Eine Auslegung für die Stufen 1 und 2 ist in der Beschreibung insofern enthalten, als die Bedingungen der Stufe 3 nur noch teilweise erfüllt werden müssen. Im Anhang E befindet sich hierzu ein Rechenbeispiel.

6.1 Festlegen der Raumheizkörperlänge und -höhe

Zum Abfangen der Fallluftströmung an der Fensterinnenseite muss der Raumheizkörper mindestens folgende Bedingungen erfüllen:

- Anordnung des Raumheizkörpers unter dem Fenster
- Länge Raumheizkörper ≈ Länge Fenster

Die Höhe des Raumheizkörpers kann frei nach ästhetischen und architektonischen Gesichtspunkten gewählt werden.

6) Für Raumheizkörper ohne Strahlungswirkung, z. B. bei Konvektoren, entfällt die Berechnung des Strahlungsausgleichs. Die Vorlauftemperatur richtet sich entweder nach der Vorlauftemperatur der übrigen Raumheizkörper mit Strahlungswirkung oder ist frei wählbar.

6 Designing of heating appliances

By way of example, the designing of heating appliances (which are effective as radiators[6)]) is described below for class 3 requirements. In the example, only the window is considered as a surface impairing comfort. Designing for classes 1 and 2 is contained in this description insofar as they only require compliance with some of the requirements of class 3. Annex E gives a calculation example for this.

6.1 Determination of the length and height of the heating appliance

The heating appliance must at least comply with the following requirements in order to counter the downdraft on the inside of the window:

- The heating appliance must be arranged under the window.
- The length of the heating appliance must approximately equal that of the window.

The height of the heating appliance may be chosen arbitrarily to match aesthetic and architectural requirements.

6) The calculation of radiation compensation will be omitted for heating appliances which are not effective as radiators, e. g. convectors. The inlet water temperature is either determined by the remaining radiators, or may be chosen arbitrarily.

6.2 Berechnung der benötigten Raumheizkörper-Übertemperatur

Zur Kompensation der „kalten" Abstrahlung z. B. eines Fensters sind von dem Raumheizkörper k folgende Bedingungen zu erfüllen:

Anordnung des Raumheizkörpers vor der gleichen Ebene wie das Fenster.

$$\Delta T_{\mathrm{H},\,k} \geq \frac{L_{\mathrm{U}j} \cdot H_{\mathrm{U}j} \cdot \Delta T_{\mathrm{U}j}}{L_{\mathrm{HK},\,k} \cdot H_{\mathrm{HK},\,k}} \tag{9}$$

Die Fensteruntertemperatur ΔT_{U} im Auslegungsfall ergibt sich dabei nach Gleichung (1) mit der Aussentemperatur ϑ_{a} entsprechend DIN pr EN 12 831 bzw. DIN 4701 oder kann entsprechend aus Bild C1 (Anhang C) entnommen werden. Die höchste der verschiedenen Übertemperaturen $\Delta T_{\mathrm{H\,max}}$ dient der Auslegung.

6.3 Bestimmung der Spreizung, Vor- und Rücklaufübertemperatur im Auslegungsfall

Die minimale Auslegungsspreizung σ_{Ausl} soll bei Raumtemperaturreglern mit bleibender Regelabweichung (z. B. Thermostatventile mit P-Verhalten) nach Bild C2 in Abhängigkeit der Wasserübertemperatur ΔT nicht unterschritten werden. Die Auslegungs-Vorlaufübertemperatur ΔT_1 wird nach Gleichung (10) aus der Summe der maximal notwendigen Raumheizflächen-Übertemperatur $\Delta T_{\mathrm{H\,max}}$ und der halben Auslegungsspreizung σ_{Ausl} berechnet. Die Auslegungs-Rücklaufübertemperatur ergibt sich aus der Differenz zwischen Auslegungs-Vorlaufübertemperatur ΔT_1 und Auslegungsspreizung σ_{Ausl} nach Gleichung (11):

$$\Delta T_1 \approx \Delta T_{\mathrm{H,\,max}} + \frac{\sigma_{\mathrm{Ausl}}}{2} \tag{10}$$

$$\Delta T_2 = \Delta T_1 - \sigma_{\mathrm{Ausl}} \tag{11}$$

Entsprechend Abschnitt 5.3 ist die Auslegungs-Vorlauftemperatur nach oben und unten beschränkt.

6.4 Bestimmung der Norm-Wärmeleistung

Dem Auslegungsdiagramm Bild C3–C6 (Anhang C) kann mit der Vor- und Rücklaufübertemperatur des Raumheizkörpers das Verhältnis $(\Phi/\Phi_{\mathrm{S}})_{\mathrm{erf}}$ entnommen werden. Mit Hilfe der Normheizlast $\dot{Q}_{\mathrm{N}}$ (bei mehreren Heizkörpern in einem Raum soll die Normheizlast entsprechend der Ansichtsflächen der Heizkörper aufgeteilt werden, lässt sich dann die geforderte Norm-Wärmeleistung $\Phi_{\mathrm{S,erf}}$ des Raumheiz-

6.2 Determination of the required excess temperature of the heating appliance

In order to compensate the "cold" radiation of, e. g., a window, the heating appliance k must fulfil the following requirements:

Heating appliance arranged in front of the window plane:

$$\Delta T_{\mathrm{H},\,k} \geq \frac{L_{\mathrm{U}j} \cdot H_{\mathrm{U}j} \cdot \Delta T_{\mathrm{U}j}}{L_{\mathrm{HK},\,k} \cdot H_{\mathrm{HK},\,k}} \tag{9}$$

The design window under temperature, ΔT_{U}, is calculated from Equation (1) using the outdoor temperature, ϑ_{a}, as per DIN pr EN 12 831 or DIN 4701, or may be obtained from Figure C1 (Annex C). The highest of the various excess temperatures, $\Delta T_{\mathrm{H\,max}}$, is used for designing purposes.

6.3 Determination of design difference between inlet and outlet water temperatures, and design inlet and outlet water excess temperatures

When using room thermostats with a steady-state deviation (such as thermostatic valves with proportional, or P, action), the minimum design difference between inlet and outlet water temperatures should not be less than the value given in Figure C2 as a function of the water excess temperature, ΔT. The design inlet water excess temperature, ΔT_1, is determined using Equation (10), from the sum of the maximum required heating-surface excess temperature, $\Delta T_{\mathrm{H\,max}}$, and half the design difference between inlet and outlet water temperatures, σ_{Ausl}. The design outlet water excess temperature results from the difference between the design inlet water excess temperature, ΔT_1, and the design difference between inlet and outlet water temperatures, σ_{Ausl}, as per Equation (11):

$$\Delta T_1 \approx \Delta T_{\mathrm{H,\,max}} + \frac{\sigma_{\mathrm{Ausl}}}{2} \tag{10}$$

$$\Delta T_2 = \Delta T_1 - \sigma_{\mathrm{Ausl}} \tag{11}$$

Upper and lower limits of the design inlet water temperature are given in Section 5.3.

6.4 Determination of standard thermal output

The ratio $(\Phi/\Phi_{\mathrm{S}})_{\mathrm{erf}}$ can be obtained from the design diagrams in Figures C3 through C6 (Annex C) with the inlet and outlet water excess temperatures of the heating appliance being input quantities. Putting in the design heating load, $\dot{Q}_{\mathrm{N}}$ (where there are several heating appliances in a room, each should be allocated a design heating load in proportion to its visible-surface area), the required standard thermal körpers nach Gleichung (12) bestimmen:

$$\Phi_{\mathrm{S,erf}} = \frac{\dot{Q}_{\mathrm{N}}}{\left(\frac{\Phi}{\Phi_{\mathrm{S}}}\right)_{\mathrm{erf}}} \quad (12)$$

6.5 Auswahl des Heizkörpermodells und Überprüfung der Ergebnisse auf Einhaltung des Gesamtziels

Durch die Abstufung der Leistungsangaben im jeweiligen Raumheizkörper-Katalog wird in der Regel eine gegenüber $\Phi_{\mathrm{S,erf}}$ niedrigere Norm-Wärmeleistung $\Phi_{\mathrm{S,ist}}$ ausgewählt, damit die mittlere Übertemperatur der Heizfläche nicht unter den nach Gleichung (9) errechneten Wert von $\Delta T_{\mathrm{H},j}$ sinkt. Dies führt bei festgehaltener Auslegungs-Vorlauftemperatur zu einer Anhebung der Heizkörper-Rücklauftemperatur und des Wasserstroms oder bei festgehaltener Spreizung zur Anhebung der Vor- und Rücklauftemperatur.

Zur Überprüfung der Kompensation der „kalten“ Abstrahlung der Umfassungsflächen muss Gleichung (13) erfüllt sein:

$$\Delta T_{\mathrm{H},j,\mathrm{ist}} = \frac{\Delta T_1 + \Delta T_{2,\mathrm{ist}}}{2} \geq \Delta T_{\mathrm{H}} \quad (13)$$

6.6 Berechnung des Wasserstroms

Die Auslegeleistung Φ_{erf} und die Ist-Spreizung σ_{ist} bestimmen den Wasserstrom nach Gleichung (14):

$$q_m = \frac{\Phi_{\mathrm{erf}}}{\sigma_{\mathrm{ist}} \cdot c_{\mathrm{p}}} \quad (14)$$

6.7 Berechnung der Aufheizreserve

Zur Berechnung der Aufheizreserve wird das Verhältnis $\Phi_{\mathrm{max}}/\Phi_{\mathrm{S}}$, ist aus dem Auslegediagramm (Bild C3–C6) bei der maximal erreichbaren Vorlauftemperatur und/oder dem maximal erreichbaren Wasserstrom abgelesen. Entsprechend wird bei der Zusatzheizfläche vorgegangen.

Schrifttum

[1] *Eckert, E. R. G.; Jackson, T. W.*: Free convection boundary layer on flat plate. National Advisory Commitee for Aeronautics (NACA), Technical Report (TR) 1015, (1951)

[2] VDI Wärmeatlas: 6. Auflage 1991, Düsseldorf: VDI-Verlag

output, $\Phi_{\mathrm{S,erf}}$, of the heating appliance can then be determined using Equation (12):

$$\Phi_{\mathrm{S,erf}} = \frac{\dot{Q}_{\mathrm{N}}}{\left(\frac{\Phi}{\Phi_{\mathrm{S}}}\right)_{\mathrm{erf}}} \quad (12)$$

6.5 Selection of a heating-appliance model and checking of the results for compliance with overall specifications

As a consequence of the steps in the ratings as quoted in the pertinent catalogue of heating appliances, the actual standard thermal output, $\Phi_{\mathrm{S,ist}}$, is usually chosen to lie below $\Phi_{\mathrm{S,erf}}$ in order to avoid a drop of the mean excess temperature of the heating surface below the value of $\Delta T_{\mathrm{H},j}$ calculated according to Equation (9). For a constant design inlet water temperature, this leads to an increased outlet water temperature and water flow rate of the heating appliance or, for a constant difference between the inlet and outlet water temperatures, to a rise in both inlet and outlet water temperatures.

In order to check the compensation of “cold” radiation from enclosing surfaces, Equation (13) must be fulfilled:

$$\Delta T_{\mathrm{H},j,\mathrm{ist}} = \frac{\Delta T_1 + \Delta T_{2,\mathrm{ist}}}{2} \geq \Delta T_{\mathrm{H}} \quad (13)$$

6.6 Calculation of water flow rate

The design thermal output, Φ_{erf}, and the actual difference between the inlet and outlet water temperatures, σ_{ist}, determine the water flow rate as per Equation (14):

$$q_m = \frac{\Phi_{\mathrm{erf}}}{\sigma_{\mathrm{ist}} \cdot c_{\mathrm{p}}} \quad (14)$$

6.7 Calculation of the heating-up reserve

In order to determine the heating-up reserve, obtain the ratio $\Phi_{\mathrm{max}}/\Phi_{\mathrm{S}}$, ist for the maximum achievable inlet water temperature and/or the maximum achievable water flow rate from the design diagram (Figures C3 through C6). Proceed accordingly for an additional heating surface.

Bibliography

[1] *Eckert, E. R. G.; Jackson, T. W.*: Free convection boundary layer on flat plate. National Advisory Commitee for Aeronautics (NACA), Technical Report (TR) 1015, (1951)

[2] VDI Wärmeatlas: 6th Edition 1991, Düsseldorf: VDI-Verlag

Anhang A Pflichtenheft Heizung

Projekt:

Gebäude:

Raumbuch				Nutzung			Auslegungsvorgaben					weitere Vorgaben	
Ebene	Bezeichnung	Raumart	Normheizlast[1]	Heizzeiten	innere Lasten[2]	Lüftungsart[3]	Innentemperatur		Anforderungsstufe	Anforderungszone[4]	Aufheizreserve Φ_{RH}[5]	Zusatz nutzen	Aufwandszahl der Nutzenübergabe $e_{1,\,max}$[6]
–	–	–	in W	von bis	hoch/niedrig	m/F	$\vartheta_{i,A}$ in °C	ϑ_{Absenk} in °C	–	in m	in W		–

1) Rechenwert der Transmissions- und Lüftungsheizlast nach DIN 4701 oder nach DIN pr EN 12831
2) Grenze zwischen niedrig und hoch: Innenlast/Normheizlast > 0.2
3) bei mech. Lüftung zusätzliche Informationen zum Zuluftstrom; sonst nur m (mechanisch) oder F (Fensterlüftung) angeben
4) Abstand zu „kalter" Umfassungsfläche in m
5) nach DIN pr EN 12 831
6) Nutzenübergabe nach VDI 2067 Blatt 20

Datum .... Auftraggeber ....

Datum .... Auftragnehmer ....

Annex A Target specification for heating systems

Project:
Building:

Specification of rooms				Use			Design specifications					Further specifications	
Level	Designa-tion	Type of room	Design heating load[1]	Heating times	internal loads[2]	Type of ventila-tion[3]	Indoor temperature		Class of require-ments	Require-ments zone[4]	Heating up reserve Φ_{RH}[5]	Addi-tional use	Effort number of benefit transfer $e_{1,\,max}$[6]
–	–	–	in Watt	from to	high/low	m/w	$\vartheta_{i,A}$ in °C	ϑ_{Absenk} in °C	–	in m	in Watt		–

1) calculated value of transmission and ventilation heating load as per DIN 4701 or DIN pr EN 12 831
2) The border between low and high lies at an internal load/design heating load ratio of more than 0,2.
3) Enter additional information on the supply air flow where forced-draft ventilation is used; otherwise only classify as m (for mechanical) or w (for window).
4) distance, in metres, to cold enclosing surface
5) as per DIN pr EN 12 831
6) effort number of benefit transfer as per VDI 2067 Part 20

Date........................ Orderer ....

Date........................ Orderer ....

Anhang B Algorithmen zum Auslegungsdiagramm

Bei der Leistungsmessung DIN-EN 442-2 wird die so genannte Norm-Kennlinie festgestellt:

$$\Phi = C \cdot \Delta t^n \qquad \text{(B1)}$$

mit

$$\Delta t = \frac{t_1 + t_2}{2} - t_r = \frac{\Delta T_1 + \Delta T_2}{2} \qquad \text{(B2)}$$

oder

$$\frac{\Phi}{\Phi_S} = \left(\frac{\Delta T}{\Delta T_S}\right)^n \qquad \text{(B3)}$$

mit

$$\Phi_S = q_{ms} \cdot c_p \cdot (t_1 - t_2)_S = q_{ms} \cdot c_p \cdot \sigma_S \qquad \text{(B4)}$$

Abweichungen von der Normkennlinie treten auf, wenn

- der Wasserstrom stark unter den Norm-Wasserstrom gedrosselt oder
- vom üblichen Anschluss (oben Vorlauf, unten Rücklauf) abgewichen wird.

Diese Einflüsse lassen sich rechnerisch erfassen unter der Annahme eines die komplexen Mischvorgänge innerhalb des Heizkörpers stark vereinfachenden Modells, als Temperatur des Beimischwasserstroms q_2 wird die des Rücklaufs angesetzt. Die Mischung bewirkt, dass die höchste Temperatur im Heizkörper $t_{1,eff}$ unterhalb der Vorlauftemperatur liegt.

$$q_m \cdot t_1 + q_2 \cdot t_2 = (q_m + q_2) \cdot t_{1,eff} \qquad \text{(B5)}$$

$$t_{1,eff} = \frac{t_1 + (b-1) \cdot t_2}{b} \qquad \text{(B6)}$$

Der die Mischvorgänge pauschal erfassende *Beimischwert b* liegt für Gliederheizkörper und Plattenheizkörper bei etwa 1,25, bei reitendem Anschluss kann er auf Werte von 7 und darüber ansteigen. Nach DIN 4703-3 können vereinfachende Annahmen getroffen werden, solange keine gemessenen Werte vorliegen:

- für Heizkörper mit oberem Vorlaufanschluss, horizontaler Verteilung und vertikaler Durch- oder Zwangsdurchströmung $b = 1$,
- für Heizkörper mit reitendem Anschluss, horizontaler Verteilung und vertikaler Durchströmung $b = 8$,

Annex B Algorithms of the design diagram

The so-called standard characteristic is determined by measuring the thermal output according to DIN EN 442-2:

$$\Phi = C \cdot \Delta t^n \qquad \text{(B1)}$$

where

$$\Delta t = \frac{t_1 + t_2}{2} - t_r = \frac{\Delta T_1 + \Delta T_2}{2} \qquad \text{(B2)}$$

or

$$\frac{\Phi}{\Phi_S} = \left(\frac{\Delta T}{\Delta T_S}\right)^n \qquad \text{(B3)}$$

where

$$\Phi_S = q_{ms} \cdot c_p \cdot (t_1 - t_2)_S = q_{ms} \cdot c_p \cdot \sigma_S \qquad \text{(B4)}$$

Deviations from the standard characteristic will occur when

- the water flow rate is reduced considerably below the standard water flow rate, or
- there are deviations from the typical type of connection (such as inlet at the top, outlet at the bottom).

A model that largely simplifies the complex mixing processes occurring in a heating appliance allows to take these effects into consideration in calculations, assuming that the temperature of the added water flow rate q_2 is the same as the outlet water temperature. As a consequence of mixing, the highest temperature in the heating appliance, $t_{1,eff}$, lies below the inlet water temperature.

$$q_m \cdot t_1 + q_2 \cdot t_2 = (q_m + q_2) \cdot t_{1,eff} \qquad \text{(B5)}$$

$$t_{1,eff} = \frac{t_1 + (b-1) \cdot t_2}{b} \qquad \text{(B6)}$$

The *mixing coefficient*, b, which subsumes the mixing processes, is approximately 1,25 for sectional and plate radiators. It can rise to values of 7 and beyond with both inlet and outlet connected at the bottom of the heating appliance. According to DIN 4703-3, the following simplifying assumptions may be made where no measured values are available:

- $b = 1$ for heating appliances where the inlet is connected at the top, distribution is horizontal, and the (natural or forced) flow through the heating appliance is vertical,
- $b = 8$ for heating appliances where both inlet and outlet are connected at the bottom, distribution is horizontal, and flow through the heating appliance is vertical,

- für Heizkörper mit reitendem Anschluss, vertikaler Verteilung und horizontaler Durchströmung $b = 10$.

Weiterhin wird angenommen, dass die wirksame Übertemperatur des Heizkörpers sich genügend genau durch die so genannte *logarithmische Übertemperatur* wiedergeben lässt (Berücksichtigung niedriger Heizmittelströme bzw. großer Temperaturspreizungen zwischen Vorlauf und Rücklauf).

$$\Delta T_{\mathrm{lg,eff}} = \frac{t_{1,\mathrm{eff}} - t_2}{\ln \dfrac{t_{1,\mathrm{eff}} - t_\mathrm{r}}{t_2 - t_\mathrm{r}}} \tag{B7}$$

Schließlich wird angenommen, dass auch der Zusammenhang zwischen der Wärmeleistung und dieser logarithmischen Übertemperatur durch eine Potenzfunktion zu beschreiben ist, allerdings mit etwas veränderter Hochzahl $n_{\mathrm{eff}} = 1{,}33$.

$$\left[\frac{\Phi}{\Phi_\mathrm{S}}\right]^{-\frac{1}{n_{\mathrm{eff}}}} = \frac{b \cdot \Delta T_{\mathrm{lg,eff,S}}}{\Delta T_1 - \Delta T_2} \cdot \ln\left(\frac{b-1}{b} + \frac{\Delta T_1}{b \Delta T_2}\right) \tag{B8}$$

Mit den vorgenannten Annahmen ist nun ein Zusammenhang zwischen der Wärmeleistung und den Übertemperaturen anzugeben.

Diese Formel liegt dem so genannten Heizkörperdiagramm zu Grunde; für den Beimischwert ist hier $b = 1{,}0$; $b = 1{,}25$ (für genauere Rechnungen); $b = 8$ und $b = 10$ eingesetzt; für die Hochzahl gilt einheitlich $n_{\mathrm{eff}} = 1{,}33$. Das gleiche Diagramm kann auch für von 1,33 abweichende Hochzahlen verwendet werden nach:

$$\frac{\Phi}{\Phi_\mathrm{S}} = \left(\frac{\Phi}{\Phi_\mathrm{S}}\right)_{\mathrm{Diagr}}^{\frac{n_{\mathrm{eff}}}{1,33}} \tag{B9}$$

- $b = 10$ for heating appliances where both inlet and outlet are connected at the bottom, distribution is vertical, and flow through the heating appliance is horizontal.

Furthermore, it is assumed that the so-called *logarithmic excess temperature* reflects the effective excess temperature of the heating appliance to sufficient accuracy (taking into account small water flow rates and large differences between the inlet and outlet water temperatures).

$$\Delta T_{\mathrm{lg,eff}} = \frac{t_{1,\mathrm{eff}} - t_2}{\ln \dfrac{t_{1,\mathrm{eff}} - t_\mathrm{r}}{t_2 - t_\mathrm{r}}} \tag{B7}$$

Finally, the assumption is made that the relation between the thermal output and this logarithmic excess temperature can also be described in terms of an exponential function, although with a slightly modified power $n_{\mathrm{eff}} = 1{,}33$.

$$\left[\frac{\Phi}{\Phi_\mathrm{S}}\right]^{-\frac{1}{n_{\mathrm{eff}}}} = \frac{b \cdot \Delta T_{\mathrm{lg,eff,S}}}{\Delta T_1 - \Delta T_2} \cdot \ln\left(\frac{b-1}{b} + \frac{\Delta T_1}{b \Delta T_2}\right) \tag{B8}$$

A relation between the thermal output and the excess temperatures can then be given on the basis of the aforementioned assumptions.

This is the formula underlying the so-called heating-appliance diagrams. Values of the mixing coefficient, $b = 1{,}0$, $b = 1{,}25$ (for more precise calculations), $b = 8$, and $b = 10$ were used. The power n_{eff} is 1,33 in all cases. However, the same diagram can be used for powers other than 1,33, using:

$$\frac{\Phi}{\Phi_\mathrm{S}} = \left(\frac{\Phi}{\Phi_\mathrm{S}}\right)_{\mathrm{Diagr}}^{\frac{n_{\mathrm{eff}}}{1,33}} \tag{B9}$$

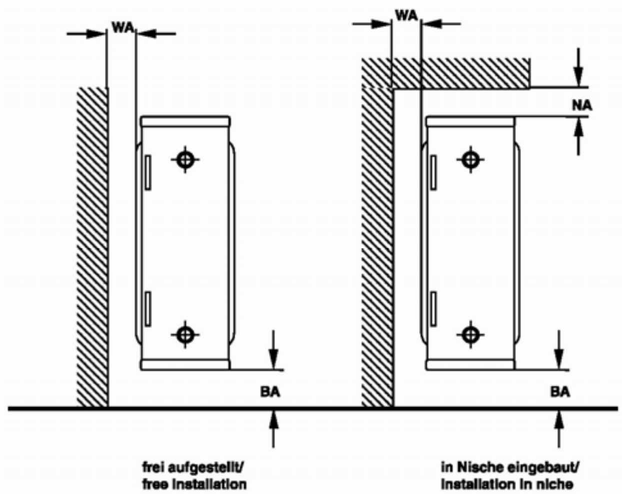


Bild B1. Einbau von Heizkörpern: Bodenabstand BA, Wandabstand WA, Nischenabstand NA

Fig. B1. Installation of heating appliances: BA is the distance from the floor, WA the distance from the wall, and NA the distance from the niche

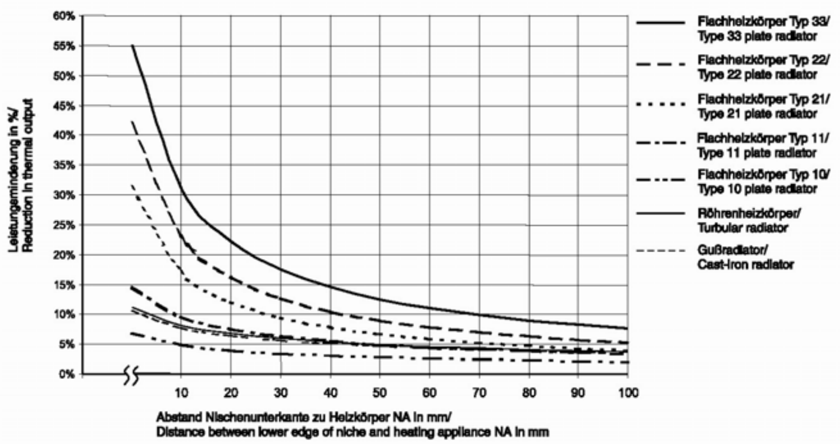


Bild B2. Leistungsminderung in Abhängigkeit des HK-Abstandes zur Nischenunterkante

Fig. B2. Reduction in thermal output as a function of the distance between the heating appliance and the lower edge of the niche

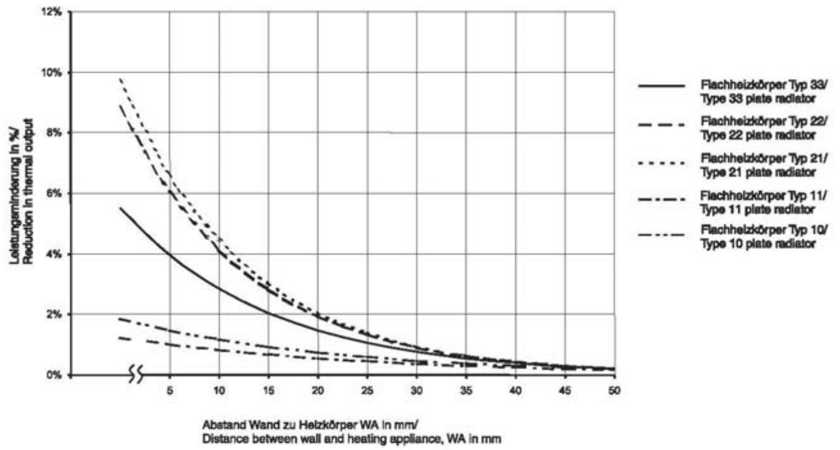


Bild B3. Leistungsminderung in Abhängigkeit vom Wandabstand des Heizkörpers

Fig. B3. Reduction in thermal output as a function of the distance between the heating appliance and the wall

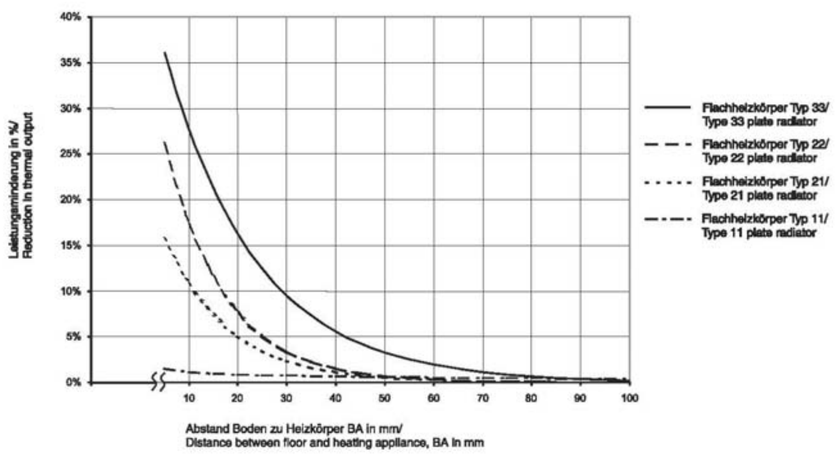


Bild B4. Leistungsminderung in Abhängigkeit vom Bodenabstand des Heizkörpers

Fig. B4. Reduction in thermal output as a function of the distance between the heating appliance and the floor

Anhang C Diagramme

Annex C Diagrams

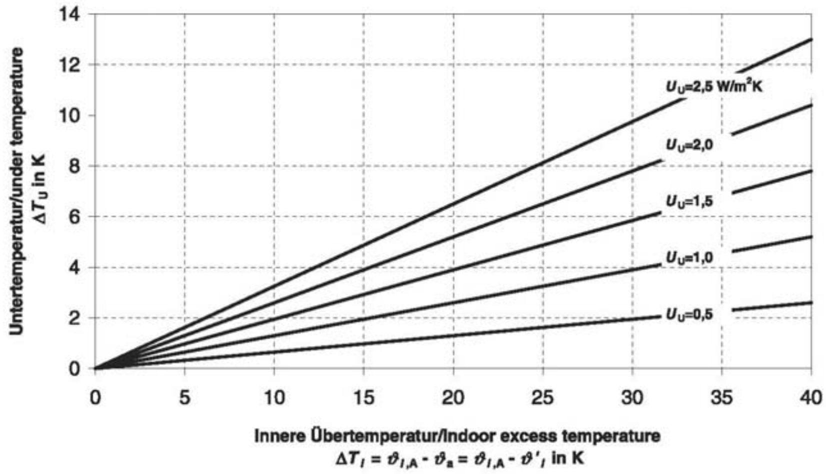


Bild C1. Untertemperatur einer Umfassungsfläche (z. B. eines Fensters) in Abhängigkeit von der inneren Übertremperatur

Fig. C1. Under temperature of an enclosing surface (such as a window) as a function of indoor excess temperature

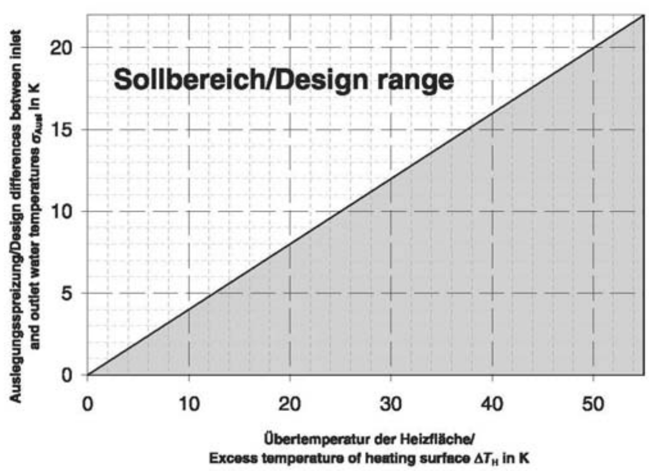


Bild C2. Mindest-Auslegungsspreizung für

$$\frac{\Delta T_1}{\sigma} = 3,0$$

Fig. C2. Minimum design difference between inlet and outlet water temperatures for

$$\frac{\Delta T_1}{\sigma} = 3,0$$

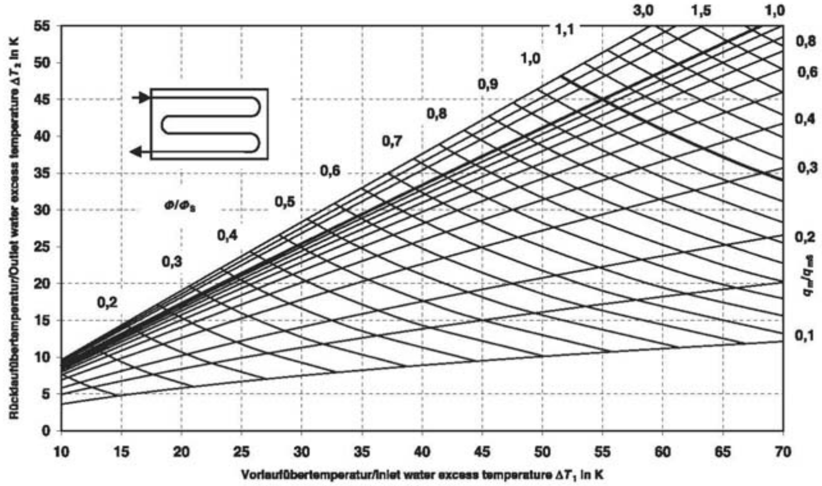


Bild C3: Heizflächen-Auslegungsdiagramm für n = 1,33 und b = 1,0 (gem. DIN 4703-3 für Heizkörper mit oberem Vorlaufanschluss, horizontaler Verteilung und vertikaler Durch- oder Zwangsdurchströmung)

Fig. C3. Heating-surface design diagram, for n = 1,33, b = 1,0 (as per DIN 4703-3 for heating appliances with inlet connected at the top, horizontal distribution, and vertical, natural or forced flow)

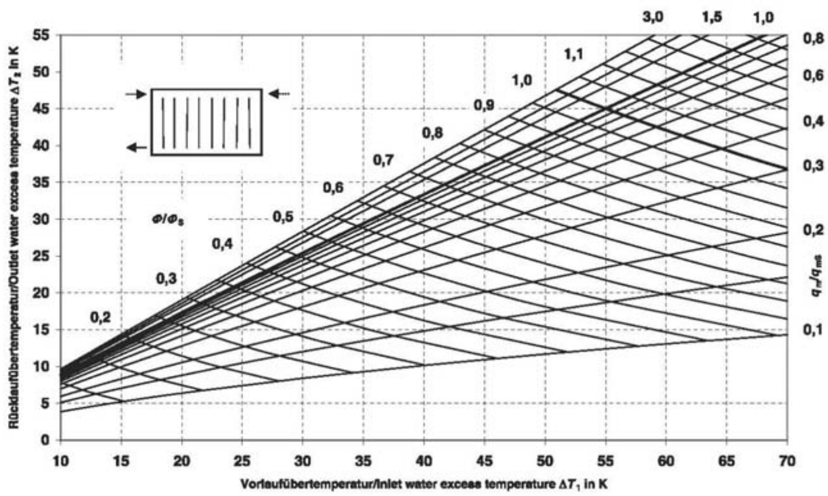


Bild C4. Heizflächen-Auslegungsdiagramm für n = 1,33 und b = 1,25 (gleich- und wechselseitiger Anschluss, genaue Auslegung)

Fig. C4. Heating-surface design diagram, for n = 1,33, b = 1,25 (inlet and outlet connected on the same side or on opposite sides, precise design)

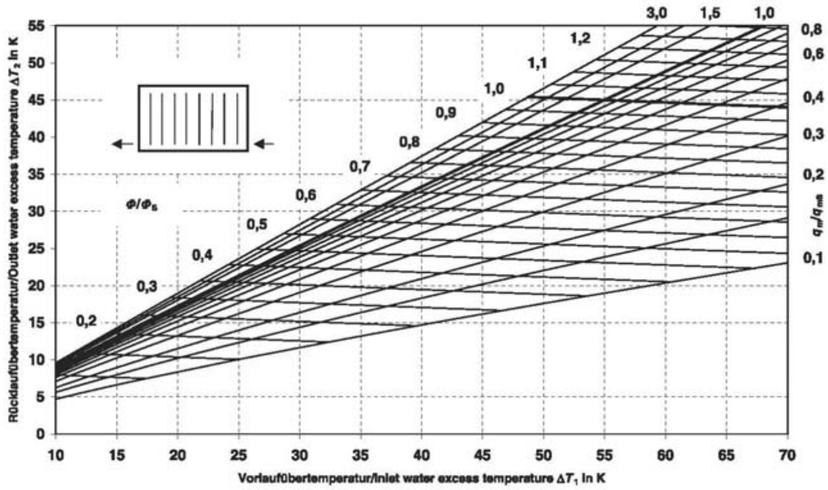


Bild C5. Heizflächen-Auslegungsdiagramm für $n = 1{,}33$ und $b = 8$ (gem. DIN 4703-3 für Heizkörper mit reitendem Anschluss, horizontaler Verteilung und vertikaler Durchströmung)

Fig. C5. Heating-surface design diagram, for $n = 1{,}33$, $b = 8$ (as per DIN 4703-3 for heating appliances with both inlet and outlet connected at the bottom, horizontal distribution, and vertical flow)

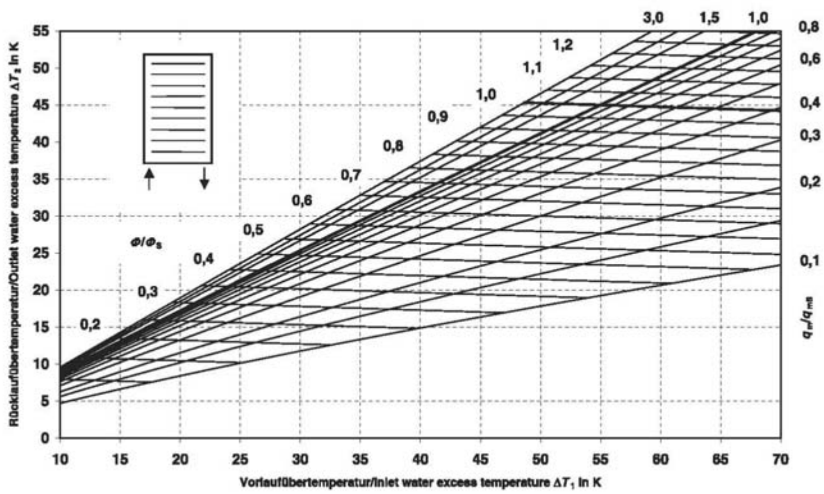


Bild C6. Heizflächen-Auslegungsdiagramm für $n = 1{,}33$ und $b = 10$ (gem. DIN 4703-3 für Heizkörper mit reitendem Anschluss, vertikaler Verteilung und horizontaler Durchströmung, z. B. Badheizkörper)

Fig. C6. Heating-surface design diagram, for $n = 1{,}33$, $b = 10$ (as per DIN 4703-3 for heating appliances with both inlet and outlet connected at the bottom, vertical distribution, and horizontal flow, such as bathroom heating appliances)

Anhang D Rechnerische Bestimmung der Grenzfläche von Anforderungszonen

Um die Wirkung eines Heizsystems auf die Behaglichkeit zu beurteilen, genügt es, die konvektive und radiative Wärmeabgabe eines Oberflächenelements einer Person zu betrachten, siehe Bild D1. Dabei wird die von einem Heizsystem (z. B. Raumheizflächen) beeinflusste thermische Umgebung (Realfall: Lufttemperatur ϑ_L, Oberflächentemperaturen der Außenwände mit Fenster ϑ_{AW}, Innenwände ϑ_{IW} oder Heizfläche ϑ_H) verglichen mit einer zum Zwecke der Auslegung vorgegebenen Einfachsituation, bei der alle Temperaturen gleich sind ($\vartheta^* = \vartheta_L = \vartheta_{AW} = \vartheta_{IW}$) und Behaglichkeit gemäß DIN ISO 7730 herrscht. Das betrachtete Oberflächenelement dA_M sei in der für die Behaglichkeitsempfindung kritischen Position, parallel zur „kalten" Umfassungsfläche (Index AW) angeordnet. Vereinfacht sind die gegebenenfalls verschiedenen kalten Umfassungsflächen (AW) und auch die wärmeren Innenflächen (IW) je zu einer zusammengefasst. Die Einstrahlzahlen φ, gekennzeichnet durch die Indizes der im Strahlungsaustausch stehenden Flächen, geben den durch die Größe und geometrische Zuordnung begrenzten Anteil des Strahlungsaustausches an. Bei dem vorliegenden Temperaturniveau und den eng beieinander liegenden Temperaturen kann für den Wärmeaustausch durch Strahlung ein linearer Zusammenhang mit einem Wärmeübergangskoeffizienten $\alpha_S = 5{,}15$ W/m²K angenommen werden. Vereinfachend gelte einheitlich für den konvektiven Wärmeübergangskoeffizienten $\alpha_K = 3$ W/m²K.

Die Wärmestromdichte $(d\dot{Q}_M/dA_M)$ beträgt beim Austausch mit der „kalten" Außenwand (AW), der Innenwand (IW), der Heizfläche (H) und der Raumluft (L):

$$\left(\frac{d\dot{Q}_M}{dA_M}\right) = \alpha_K \cdot (\vartheta_M - \vartheta_L) + \alpha_s \cdot [\varphi_{M,AW} \cdot (\vartheta_M - \vartheta_{AW}) + \varphi_{M,H} \cdot (\vartheta_m - \vartheta_H) + (1 - \varphi_{M,AW} - \varphi_{M,H}) \cdot (\vartheta_M - \vartheta_{IW})] \quad (D1)$$

Bei der vorgegebenen Idealsituation ist die Wärmestromdichte

$$\left(\frac{d\dot{Q}_M}{dA_M}\right)^* = (\vartheta_M - \vartheta^*) \cdot (\alpha_K + \alpha_S) \quad (D2)$$

Annex D Calculation of the boundary surfaces of requirements zones

For assessing the effect of a heating system on comfort, it is sufficient to consider the loss of heat, by convection and radiation, from a body surface element, see Figure D1. For the purposes of this consideration, a thermal environment [where the actual temperatures are ϑ_L (air), ϑ_{AW} (exterior walls with windows), ϑ_{IW} (interior walls), and ϑ_H (heating surface)] which is influenced by a heating system (such as heating surfaces) is compared with a simplified situation that is specified for design purposes. In this simplified situation, all temperatures are identical ($\vartheta^* = \vartheta_L = \vartheta_{AW} = \vartheta_{IW}$), and thermal comfort as per DIN ISO 7730 exists. Let the surface element in question, dA_M, lie at the position which is critical for the feeling of comfort, i.e. parallel to the "cold" enclosing surface (subscript AW). For simplification purposes, cold enclosing surfaces (AW) as well as the warmer interior surfaces (IW) are treated as one surface of each type. (Several different surfaces of both types may exist.) The radiation coefficients, φ, with subscripts identifying the respective surfaces between which radiation is exchanged, indicate the exchange of radiation as limited by the dimensions and the geometrical arrangement of the surfaces. For the temperatures in question, which do not differ greatly, a linear function with a heat transfer coefficient $\alpha_S = 5{,}15$ W/m²K can be assumed to hold for the exchange of heat by radiation. For simplification, let $\alpha_K = 3$ W/m²K for convection.

The heat flow density $(d\dot{Q}_M/dA_M)$ for exchange with the "cold" exterior wall (AW), the interior wall (IW), the heating surface (H), and the indoor air (L) is:

$$\left(\frac{d\dot{Q}_M}{dA_M}\right) = \alpha_K \cdot (\vartheta_M - \vartheta_L) + \alpha_s \cdot [\varphi_{M,AW} \cdot (\vartheta_M - \vartheta_{AW}) + \varphi_{M,H} \cdot (\vartheta_m - \vartheta_H) + (1 - \varphi_{M,AW} - \varphi_{M,H}) \cdot (\vartheta_M - \vartheta_{IW})] \quad (D1)$$

The heat flow density in the assumed idealised situation is

$$\left(\frac{d\dot{Q}_M}{dA_M}\right)^* = (\vartheta_M - \vartheta^*) \cdot (\alpha_K + \alpha_S) \quad (D2)$$

Der Wärmeabgabevergleich lautet:

$$\left(\frac{\mathrm{d}\dot{Q}_M}{\mathrm{d}A_M}\right)^* - \left(\frac{\mathrm{d}\dot{Q}_M}{\mathrm{d}A_M}\right) = \alpha_K \cdot (\vartheta_M - \vartheta^*_L) + \alpha_s \cdot [\varphi_{M,H} \cdot (\vartheta_H - \vartheta^*) + (1 - \varphi_{M,AW} - \varphi_{M,H}) \cdot (\vartheta_{IW} - \vartheta^*) - \varphi_{M,AW} \cdot (\vartheta^* - \vartheta_{AW})] \quad \text{(D3)}$$

Der Wärmeabgabevergleich wird beispielhaft berechnet für einen Raum, der 4 m breit, 5 m tief und 2,5 m hoch ist.

Als Heizfläche sei eine einfache Heizplatte von 0,5 m Höhe und 4 m Breite angenommen; die mittlere Oberflächentemperatur soll 52 °C betragen. Die mittlere Temperatur der restlichen Außenwandfläche sei hier 12 °C, die Temperatur der Innenwände und der Luft 20 °C.

Mit der Heizfläche wird das Strahlungsdefizit durch die „kalte“ Umfassungsfläche (Fenster) ausgeglichen, wenn Gleichung (D4) gilt:

$$\left(\frac{\mathrm{d}\dot{Q}_M}{\mathrm{d}A_M}\right)^* - \left(\frac{\mathrm{d}\dot{Q}_M}{\mathrm{d}A_M}\right) = 0 \quad \text{(D4)}$$

Gleichung (D3) ergibt mit den beispielhaft gegeben Werten:

$$3\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}} \cdot (20°\mathrm{C} - 20°\mathrm{C}) + 5,15\,\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}} [\varphi_{M,H} \cdot (52\,°\mathrm{C} - 20\,°\mathrm{C}) + (1 - \varphi_{M,AW} - \varphi_{M,H}) \cdot (20\,°\mathrm{C} - 20\,°\mathrm{C}) - \varphi_{M,AW}(20\,°\mathrm{C} - 12\,°\mathrm{C})] = 0 \quad \text{(D5)}$$

oder:

$$4\varphi_{M,H} - \varphi_{M,AW} = 0 \quad \text{(D6)}$$

Zur Darstellung der Grenzfläche können die Einstrahlzahlen z. B. dem VDI Wärmeatlas [2] entnommen werden. Für das oben beschriebene Beispiel ergibt sich die in Bild D2 dargestellte Grenzfläche der Anforderungszone.

The difference in heat losses is:

$$\left(\frac{\mathrm{d}\dot{Q}_M}{\mathrm{d}A_M}\right)^* - \left(\frac{\mathrm{d}\dot{Q}_M}{\mathrm{d}A_M}\right) = \alpha_K \cdot (\vartheta_M - \vartheta^*_L) + \alpha_s \cdot [\varphi_{M,H} \cdot (\vartheta_H - \vartheta^*) + (1 - \varphi_{M,AW} - \varphi_{M,H}) \cdot (\vartheta_{IW} - \vartheta^*) - \varphi_{M,AW} \cdot (\vartheta^* - \vartheta_{AW})] \quad \text{(D3)}$$

By way of example, the difference in heat losses is calculated for a room that is 4 m in width, 5 m in length and 2,5 m high.

The assumed heating surface is a simple heating plate, 0,5 m high and 4 m wide. Let its mean surface temperature be 52 °C, the mean temperature of the remaining exterior-wall surface 12 °C, and the temperature of interior walls and air 20 °C.

The heating surface will compensate the radiation deficit caused by the “cold” enclosing surface (window) if Equation (D4) holds true:

$$\left(\frac{\mathrm{d}\dot{Q}_M}{\mathrm{d}A_M}\right)^* - \left(\frac{\mathrm{d}\dot{Q}_M}{\mathrm{d}A_M}\right) = 0 \quad \text{(D4)}$$

Using the values given as examples, Equation (D3) gives:

$$3\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}} \cdot (20°\mathrm{C} - 20°\mathrm{C}) + 5,15\,\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}} [\varphi_{M,H} \cdot (52\,°\mathrm{C} - 20\,°\mathrm{C}) + (1 - \varphi_{M,AW} - \varphi_{M,H}) \cdot (20\,°\mathrm{C} - 20\,°\mathrm{C}) - \varphi_{M,AW}(20\,°\mathrm{C} - 12\,°\mathrm{C})] = 0 \quad \text{(D5)}$$

or:

$$4\varphi_{M,H} - \varphi_{M,AW} = 0 \quad \text{(D6)}$$

The radiation coefficients needed for illustration of the boundary surfaces may, e. g., be taken from the VDI Wärmeatlas [2]. For the above example, the boundary surface of the requirements zone is illustrated in Figure D2.

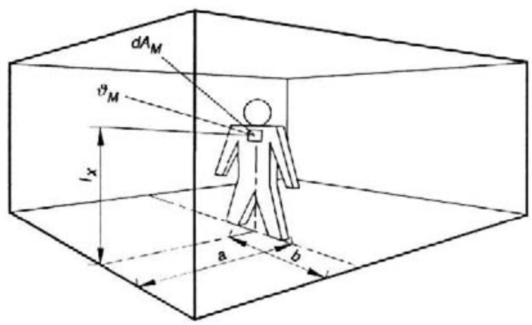


Bild D1. Person im Strahlungsaustausch

Fig. D1. Heat exchange of a person

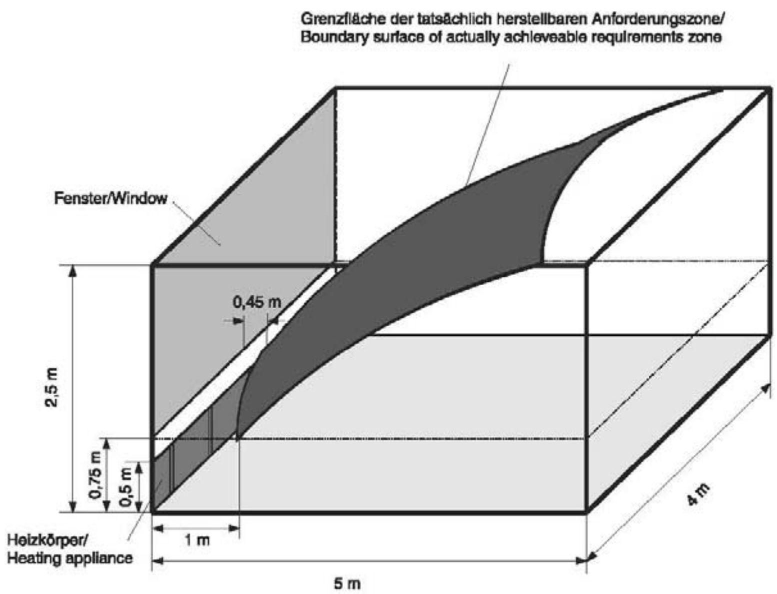


Bild D2. Beispiel für die Grenzfläche der tatsächlich herstellbaren Anforderungszone (mit Anforderungsstufe 3), die vereinfachten geraden Grenzflächen der Anforderungszone für das Pflichtenheft zeigt Bild 1

Fig. D2. Example of boundary surface of actually achievable requirements zone (with class 3 requirements); the simplified straight boundary surfaces of the requirements zone used in the target specification are shown in Figure 1.

Anhang E Konzeptionsbeispiele und Beispielrechnung

Konzeptionsbeispiel 1: Aufenthaltsraum

Vorgabe:

- Anforderungsstufe 3 (Oberflächentemperatur der „kalten" Umfassungsfläche 4 K kälter als Auslegungs-Innentemperatur)
- Maximal ausgedehnte Anforderungszone (Abstand zur „kalten" Umfassungsfläche 1 m)
- Aufheizreserve nach DIN pr EN 12 831: $\Phi_{RH} = 30\ W/m^2$

Ausführung:

Heizkörper unter dem Fenster (siehe 4.2.5, Anforderungsstufe 3)

Alternative Ausführung:

Würde ein Konvektor (ohne Strahlungswirkung) eingebaut oder der Heizkörper an der Innenwand angebracht, könnte nur Anforderungsstufe 1 erreicht werden (also Vorgabe nicht eingehalten).

Annex E Design examples and example calculation

Design example 1: Day room

Specification:

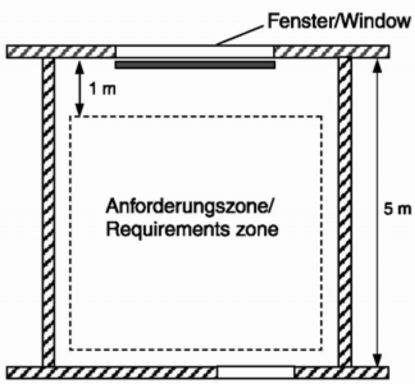
- Class 3 requirements (surface temperature of "cold" enclosing surface 4 K less than design indoor temperature)
- Maximum extension of requirements zone (distance to "cold" enclosing surface: 1 m)
- Heating-up reserve as per DIN pr EN 12 831: $\Phi_{RH} = 30\ W/m^2$

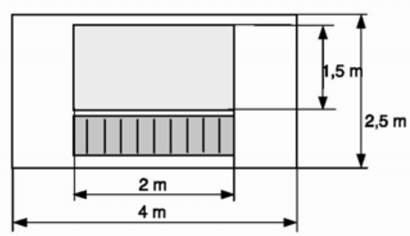
Realisation:

Heating appliance below window (see Section 4.2.5, class 3 requirements)

Alternative specification:

If a convector were used (no heat radiation), or if the heating appliance were installed on the interior wall, only class 1 requirements could be fulfilled (which means that the specification would not be met).





Konzeptionsbeispiel 2: Komfortables Wohnzimmer

Vorgabe:

- Anforderungsstufe 3 (Oberflächentemperatur der „kalten" Umfassungsfläche 4 K kälter als Auslegungs-Innentemperatur)
- Anforderungszone ergibt sich aus Raumgestaltung (max. mögliche Heizkörperhöhe) und vorgegebener Nutzung, siehe Zeichnung

Ausführung:

Heizkörper unter dem Fenster und neben der Terrassentür (siehe Abschnitt 4.2.5, Anforderungsstufe 3); der größere Abstand von Fenster 1 ermöglicht Ausgleich des Strahlungsdefizits durch Fenster 1 und des Defizits durch Fallluft an der Terrassentür; in der Anforderungszone ist Anforderungsstufe 3 erfüllt (dass hier der Abstand von 2 m ausreicht, ließe sich mit Anhang D nachweisen).

Alternative Vorgabe:

Soll der Abstand zur „kalten" Umfassungsfläche im Bereich des Fenster 1 nur 1 m betragen wäre mit der so vergrößerten Anforderungszone nur Anforderungsstufe 2 einzuhalten.

Design example 2: Comfortable living-room

Specification:

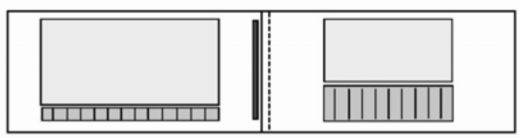
- Class 3 requirements (surface temperature of "cold" enclosing surface 4 K less than design indoor temperature)
- The requirements zone is determined by the room design (maximum possible height of heating appliances) and the intended use, see Figure

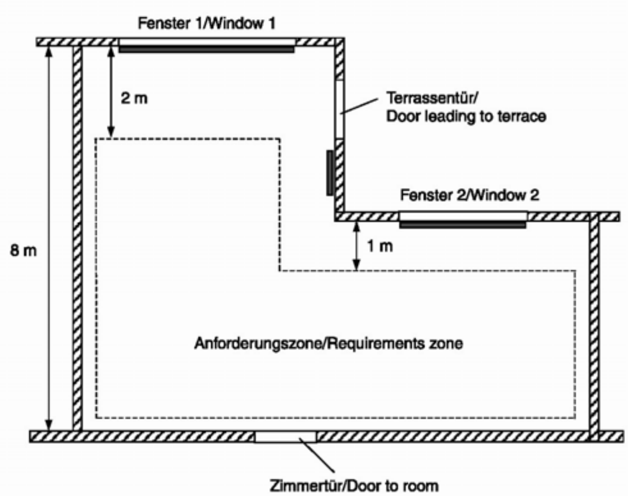
Realisation:

Heating appliances below the windows and to the side of the door leading to the terrace (see Section 4.2.5, class 3 requirements). The greater distance from window 1 allows compensating the radiation deficit due to window 1 and the deficit due to the downdraft at the door leading to the terrace; class 3 requirements are fulfilled within the requirements zone. (It could be shown using Annex D that the distance of 2 m is sufficient here.)

Alternative specification:

If the distance to the "cold" enclosing surface in the area of window 1 were to be reduced to 1 m, the requirements zone thus expanded would only allow to fulfil class 2 requirements.





Konzeptionsbeispiel 3: Zimmer im Studentenwohnheim

Vorgabe:

- Anforderungsstufe 2
- Anforderungszone ergibt sich aus Raumgestaltung und vorgegebener Nutzung, siehe Zeichnung.

Ausführung:

Heizkörper zwischen Fenster und Terrassentür (siehe Abschnitt 4.2.5, Anforderungsstufe 2).

Alternative Ausführung:

Durch die Montage des Heizkörpers an der Innenwand würde nur Anforderungsstufe 1 erreicht.

Design example 3: Room in a student hostel

Specification:

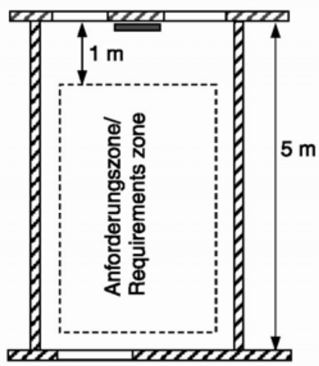
- Class 2 requirements
- The requirements zone is determined by the room design (maximum available height of heating appliances) and the intended use, see Figure.

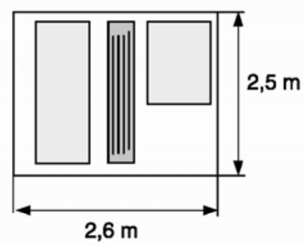
Realisation:

Heating appliances between the window and the door to the terrace (see Section 4.2.5, class 2 requirements).

Alternative specification:

Installing a heating appliance on the interior wall would only allow to fulfil class 1 requirements.





Beispielrechnung

Aufgabe:

Für den Aufenthaltsraum aus Konzeptionsbeispiel 1 mit den angeführten Vorgaben soll die Raumheizfläche ausgelegt werden.

Vorgegebene Daten:

Auslegungs-Innentemperatur:

$\vartheta_{i,A} = 22\ °C$

Normheizlast:

$\dot{Q}_N = 760\ W$

Raummaße:

Breite = 4 m

Tiefe = 5 m

Höhe = 2,5 m

Fenstermaße:

Breite $L_{Fe} = 2\ m$

Höhe $H_{Fe} = 1,5\ m$

Fenster:

U-Wert $U_{Fe} = 1,3\ W/(m^2K)$

Wärmeübergangswiderstand $1/\alpha_i = 0,13\ (m^2K)/W$ (aus Tabelle 1)

Außentemperatur:

Auslegefall $\vartheta_a = -14\ °C$

Aufheizreserve nach DIN pr EN 12 831:

$\Phi_{RH} = 30\ W/m^2$

Auslegung des Raumheizkörpers:

1. Festlegen der Anordnung und Länge der Raumheizfläche:
   - Anordnung der Raumheizfläche unter dem Fenster
   - Länge Raumheizfläche = Länge Fenster $L_{HK} = 2\ m$
   - Höhe der Raumheizfläche (gewählt) $H_{HK} = 0,5m$
2. Berechnung der benötigten Raumheizflächen-Übertemperatur:

$$\Delta T_U = \frac{U_U}{\alpha_i}(\vartheta_{i,A} - \vartheta_a)$$

Example calculation

Problem:

To design a heating surface fulfilling the specifications listed for the day room in example 1.

Specifications:

Design indoor temperature:

$\vartheta_{i,A} = 22\ °C$

Design heating load:

$\dot{Q}_N = 760\ W$

Dimensions of the room:

Width = 4 m

Length = 5 m

Height = 2,5 m

Dimensions of window:

Width $L_{Fe} = 2\ m$

Height $H_{Fe} = 1,5\ m$

Window:

U-value $U_{Fe} = 1,3\ W/(m^2K)$

Heat transfer resistance $1/\alpha_i = 0,13\ (m^2K)/W$ (from Table 1)

Outdoor temperature:

Design case $\vartheta_a = -14\ °C$

Heating-up reserve as per DIN pr EN 12 831:

$\Phi_{RH} = 30\ W/m^2$

Designing of heating appliance:

1. Specification of arrangement and length of the heating surface:
   - heating surface arranged under the window
   - length of heating surface equals length of window: $L_{HK} = 2\ m$
   - height of heating surface (chosen) $H_{HK} = 0,5\ m$
2. Calculation of required temperature of heating surface:

$$\Delta T_U = \frac{U_U}{\alpha_i}(\vartheta_{i,A} - \vartheta_a)$$

- Fenster-Untertemperatur nach Gl. (1):
  $\Delta T_{Fe} = 6{,}1$ K
- Raumheizflächen-Übertemperatur nach Gl. (9):

$$\Delta T_H \geq \frac{L_{Fe} \cdot H_{Fe} \cdot \Delta T_{Fe}}{L_{HK} \cdot H_{HK}}$$

$\Delta T_H = 18{,}3$ K

3. Auslegungsspreizung:
   - aus Bild C2
     $\sigma_{Ausl} = 7{,}5$ K

4. Vorlauf-Übertemperatur aus Gl. (10):

$$\Delta T_{1,soll} = \Delta T_{H,max} + \frac{\sigma_{Ausl}}{2}$$

$\Delta T_{1,soll} = 22{,}05$ K
da $t_{1,min} = 45$ °C:
$\Delta T_{1,soll} = 45$ °C - 22 °C
$\Delta T_{1,soll} = 23$ K

5. Rücklauf-Übertemperatur aus Gl. (11):
   $\Delta T_{2,soll} = \Delta T_1 - \sigma_{Ausl}$
   $\Delta T_{2,soll} = 23$ K - 7,5 K
   $\Delta T_{2,soll} = 15{,}5$ K

6. Bestimmung der Normwärmeleistung
   - aus Heizkörperauslegediagramm Bild C3
     $\Phi / \Phi_S = 0{,}28$
   - Normwärmeleistung nach Gl. (12):

$$\Phi_{S,erf} = \frac{\dot{Q}_N}{\left(\frac{\Phi}{\Phi_S}\right)_{erf}}$$

$\Phi_{S,erf} = 2714$ W

7. Auswahl des Heizkörpers aus dem Heizkörper-Katalog, Φ_S für 75/65:
   - Gewählt: 2000/500 Typ 21
     $\Phi_{S,ist} = 2400$ W
   - Verhältnis der Wärmeleistung $\Phi / \Phi_{S,ist}$

$$\frac{\Phi}{\Phi_{S,ist}} = \frac{760}{2400}$$

$\Phi / \Phi_{S,ist} = 0{,}317$

Bei $\Delta T_1 = 23$ K wäre $\Delta T_2 = 18{,}5$ K und $\sigma = 4{,}5\text{ K} < \sigma_{min}$

- Under temperature of window as per Equation (1):
  $\Delta T_{Fe} = 6{,}1$ K
- excess temperature of heating surface as per Equation (9):

$$\Delta T_H \geq \frac{L_{Fe} \cdot H_{Fe} \cdot \Delta T_{Fe}}{L_{HK} \cdot H_{HK}}$$

$\Delta T_H = 18{,}3$ K

3. Design difference between inlet and outlet water temperatures:
   - from Figure C2
     $\sigma_{Ausl} = 7{,}5$ K

4. Inlet water excess temperature as per Equation (10):

$$\Delta T_{1,soll} = \Delta T_{H,max} + \frac{\sigma_{Ausl}}{2}$$

$\Delta T_{1,soll} = 22{,}05$ K
da $t_{1,min} = 45$ °C:
$\Delta T_{1,soll} = 45$ °C - 22 °C
$\Delta T_{1,soll} = 23$ K

5. Outlet water excess temperature as per Equation (11):
   $\Delta T_{2,soll} = \Delta T_1 - \sigma_{Ausl}$
   $\Delta T_{2,soll} = 23$ K - 7,5 K
   $\Delta T_{2,soll} = 15{,}5$ K

6. Determination of standard thermal output
   - from heating-appliance design diagram Figure C3
     $\Phi / \Phi_S = 0{,}28$
   - standard thermal output as per Equation (12):

$$\Phi_{S,erf} = \frac{\dot{Q}_N}{\left(\frac{\Phi}{\Phi_S}\right)_{erf}}$$

$\Phi_{S,erf} = 2714$ W

7. Selection of heating appliance from heating-appliance catalogue, Φ_S for 75/65:
   - selected: 2000/500, type 21
     $\Phi_{S,ist} = 2400$ W
   - ratio of thermal outputs $\Phi / \Phi_{S,ist}$

$$\frac{\Phi}{\Phi_{S,ist}} = \frac{760}{2400}$$

$\Phi / \Phi_{S,ist} = 0{,}317$

$\Delta T_1 = 23$ K would result in $\Delta T_2 = 18{,}5$ K, and $\sigma = 4{,}5\text{ K} < \sigma_{min}$

8. Anheben der Vorlauftemperatur wegen σ_{min} auf: $\Delta T_1 = 25$ K

9. Rücklauftemperatur für Heizkörper bei $\Phi/\Phi_{S,ist}$

   – aus Heizkörperauslegungsdiagramm Bild C3 $\Delta T_{2,ist} = 17$ K

   – Rücklauftemperatur $t_2 = \Delta T_{2,ist} + \vartheta_{i,A}$ $t_2 = 39$ °C

10. Wasserstrom für σ_{Ausl} nach Gl.(14) $q_m = 0{,}0227$ kg/s $q_m = 81{,}82$ kg/h

11. Überprüfung der Ergebnisse

    – Raumheizflächen-Übertemperatur nach Gl. (13)

$$\Delta T_{H,j,ist} = \frac{\Delta T_1 + \Delta T_{2,ist}}{2} \geq \Delta T_H$$

$\Delta T_{H,ist} = 21$ K $> 18{,}3$ K Gl. (13) erfüllt

12. Überprüfung der Aufheizreserve

    Annahmen: Vorlauftemperaturanhebung zu Aufheizzwecken auf $t_1 = 65$ °C, keine Anhebung des Massenstroms (q_m/q_{mS} = const.)

    – aus Heizkörperdiagramm Bild C3 $\Phi_{max}/\Phi_{S,ist} = 0{,}62$ $\Phi_{max} = 1488$ W

    $\Delta\Phi_{RH,j} = \Phi_{max} - \Phi_{erf}$

    $= 1488$ W $- 760$ W $= 728$ W $> \Phi_{RH,soll}$

    => Aufheizreserve durch Betriebsheizfläche ausreichend!

8. Increase of inlet water temperature because of σ_{min} to: $\Delta T_1 = 25$ K

9. Outlet water temperature for heating appliance at $\Phi/\Phi_{S,ist}$

   – from heating-appliance design diagram Figure C3 $\Delta T_{2,ist} = 17$ K

   – outlet water temperature $t_2 = \Delta T_{2,ist} + \vartheta_{i,A}$ $t_2 = 39$ °C

10. Water flow rate for σ_{Ausl} as per Equation (14) $q_m = 0{,}0227$ kg/s $q_m = 81{,}82$ kg/h

11. Check of results

    – heating-surface excess temperature as per Equation (13)

$$\Delta T_{H,j,ist} = \frac{\Delta T_1 + \Delta T_{2,ist}}{2} \geq \Delta T_H$$

$\Delta T_{H,ist} = 21$ K $> 18{,}3$ K fulfils Equation (13)

12. Check of heating-up reserve

    Assumptions: Increase of inlet water temperature to $t_1 = 65$ °C for the purpose of heating up, no increase in mass flow (q_m/q_{mS} = const.)

    – from heating-appliance design diagram Figure C3 $\Phi_{max}/\Phi_{S,ist} = 0{,}62$ $\Phi_{max} = 1488$ W

    $\Delta\Phi_{RH,j} = \Phi_{max} - \Phi_{erf}$

    $= 1488$ W $- 760$ W $= 728$ W $> \Phi_{RH,soll}$

    => sufficient heating-up reserve provided by normal-duty heating surface!

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14. ABSTRACT

An energy and process optimization assessment (EPOA) study was conducted at selected U.S. Army installations in Germany and at two U.S. Army Garrison Wiesbaden schools to identify potential for energy conservation at those locations. The study identified energy conservation, process optimization, and environmental improvement opportunities that could significantly reduce operating costs and improve the installations' mission readiness and competitive position. Eighty five energy conservation measures (ECMS) were identified, most of which were quantified economically; if implemented, these ECMS would reduce annual electrical energy consumption by approximately 2412 MWH, thermal heating consumption by 17277 MWH, and total operating costs by approximately $1.4 million/yr. Implementation of all these ECMS would cost approximately $9.7 million and would yield an average simple payback of 7.2 yrs. The study recommends that these potential cost savings be aggressively pursued with an program of energy and process optimization. A separate level I EPOA study of the industrial complex at the Germersheim DDDE and a Level II EPOA study at the flight simulator building in Illesheim were also recommended, since these locations both show potential for significant reductions in energy use and operating cost, and for improvement in worker productivity.

15. SUBJECT TERMS

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